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THE OUTLOOK FOR THE FUTURE—NON-RENEWABLE RESOURCES [1]

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ONE of the problems facing modern civilization is that presented by an expanding population which is dependent on an economy based on continually available supplies of mineral raw materials, the total amount of which is fixed. This dilemma of an assumed infinite population in a finite world with finite nonrenewable resources, is one that has no simple solution, for no amount of legislation or foreseeable research on nonrenewable resources will ever create new deposits of these resources, as this would require speeding up geologic processes to a rate commensurate with the rate of population increase.

Most of the current proposals to alleviate this basic problem have been in considerable part based on political or economic actions. They are efforts to solve the short-term aspects of the problem: a natural consequence of the fact that, on the one hand, economic and social development has progressed much more rapidly in some parts of the world than others, and on the other hand, that the nonrenewable resources are not uniformly distributed throughout the world.

Increasingly, however, we must consider longer-range plans. The apparent lack of a solution to the basic dilemma, because of our inability to control geologic processes, does not mean that we cannot reach a solution that is good for a finite and relatively small number of future generations through the creation of new resource potentials. There are in fact sound grounds for believing that requirements for this immediate future can be met if we start now on a vigorous program of basic and applied research along several lines of geologic and engineering activity that may be expected to accomplish such a result.

Actually, the distinction between the political and economic short term actions and the long range scientific and technical programs is an oversimplification. So long as we have separate governments, and national boundaries

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that separate erratically distributed deposits of nonrenewable resources of varying quality, political and economic factors will continue to be operative and will materially modify any of the results that may obtain from the longer-range research that is the concern of this paper. Study of these non-technical problems should therefore proceed concomitantly with the longer range technical research.

Three broad fields of the long range research appear to be especially promising. They are:

First, research that is directed toward a better understanding of the origin of the mineral deposits now being worked; and related applied research that is aimed at the development of tools by which we can detect such deposits when they are not exposed at the earth's surface.

Second, research that is directed toward a better knowledge of the distribution of elements in the earth's crust in concentrations that are too small to be presently workable; and related applied research on new techniques that might make it possible to convert such material into a useful resource.

Third and finally, research into the basic physical and chemical properties of the nonrenewable resources, with the objective of developing synthetic or substitute materials from either renewable resources or from more abundant and more accessible nonrenewable materials. In this field, there is also a need for the development of methods by which the general population may be persuaded to accept substitute materials that are equally well adapted in their physical and chemical properties but are unfamiliar in name or appearance.

Now I would like to discuss more fully each of these three fields, with the full realization that predictions as to either the course or results of research for more than a few years in advance are speculative in the extreme.

Research along lines designed to extend supplies of resources in the grade and quality of those that are now being worked is likely to be considered the most attractive for immediate applicability of results. It is also one for which there is a larger base of past accomplishments on which to build; and also, in the view of many economic geologists, research along these lines is most likely to provide rich rewards.

At the risk of over-simplification, we may distinguish three general classes of resources in so far as exploration is concerned. Each presents a somewhat different research requirement.

The first class includes such materials as coal, limestone, and gravel. These commodities occur as what D. H. McLaughlin (13) calls plenemensurate deposits—extensive layers close to the surface of the earth and generally uniform in composition. The quantities of the material present are capable of being fully measured and sampled in the early stages of their exploration, and most commodities that occur in this form are found in amounts that are more than adequate for our needs for many years, or even centuries. They pose few problems in exploration for the research geologist.

A second class of commodity normally occurs as concentrations within such sedimentary layers. The concentration into workable deposits may have occurred either during or after the deposition of the sedimentary layers by

one or another of several different mechanisms. Oil, potash, and some iron ore deposits are examples of such commodities. For petroleum, particularly, there have been comprehensive, and very well supported, research programs over the past 30 years directed on the one hand toward the origin of the substance and the factors that control its migration and entrapment, and, on the other hand, toward the development of tools by which either the concentrations or the geological features related to the concentrations can be determined beneath the earth's surface, sometimes at very considerable distances beneath the surface.

These programs have been extremely successful in maintaining our known proven petroleum reserves at a high level for a number of years past. We can safely predict that these research programs will continue to be supported —probably on an increasingly large scale. Present tendencies suggest that future research in the fields that are applicable to this class of deposit will be more and more directed toward the solution of basic geologic problems and will be designed to help us better understand and predict where oil accumulates, and will be carried on concurrently with applied research in petroleum engineering on improvement of secondary recovery methods.

This pattern of research may be just well under way for the third class of resources—those that are formed as a result of processes related to the emplacement of bodies of igneous rock. Compared to the deposits of the other two classes, these are small and erratically distributed. Most of the commodities that are involved, such as copper, lead, zinc, tungsten, talc, are those for which increasing concern is expressed in regard to our future supply.

Research directed toward an understanding of the origin of these deposits and of the factors that localized them will be difficult and wide-ranging, since we must ultimately have to understand such fundamental questions as why granite masses are located where they are, and the mechanics of formation of folds and fractures in the earth's crust. Similarly, the development of tools to locate concealed deposits of these commodities, whose existence is suspected on theoretical grounds, will be a difficult task as targets to be looked for are much smaller than those of the petroleum geophysicists, and the differences to be measured in the physical properties of favorable or unfavorable rock are also minute.

Research to find deposits of this third class of resource has lagged, especially in comparison with petroleum, only in part because of the difficult problems to be solved. A more potent cause has been the fact that until recently discovery of deposits at the earth's surface has been so easily accomplished that the need for such research has not been pressing.

We are now approaching a time when the easily-found deposits in the better known parts of the world have been brought into production and trade barriers have made foreign exploration for new surface finds much less attractive.

A number of mining companies in the past few years have embarked on programs of research (both basic and applied) in the field of exploration in the hope of improving their capacity to find new deposits.

Just what are the chances that such research will be successful? What direction should it take?

There are sound grounds for believing that the results of research of this sort will be productive. The known deposits of this character are, first of all, generally restricted to particular geological provinces—those in which there has been mountain building at some time in the geologic past. There is some evidence to suggest, moreover, that in very large areas within these particular geologic provinces a roughly constant total amount of ore material has been introduced by the processes of mineralization and that, in addition, the quantitative distribution of this ore material into separate mining districts has also been relatively constant (14).

The mineral deposits of these commodities that we are mining now or which were mined in the past—if some broad assumptions may be made as to the average case—probably represent only those that were found at the present surface or that occurred in the upper 200 feet of the surface. If we now assume that a uniform original distribution would provide each 200-foot slice of the crust with the same amount of material down to a depth of a thousand feet, which is an approximation of the average economic limit of exploitation, then we have as the possible objective of research on this class of mineral resource a potential of something in the order of five times the presently known supply. Over a good part of these favorable geological provinces, furthermore, something like half of the present surface provides exposures of the ore-bearing environment—the rest being covered by younger, post-ore rocks.

Probably most mining geologists are in agreement that future research will succeed in finding a large proportion of these hidden ore bodies as well as assisting in the less exciting, but perhaps more immediately rewarding, job of finding extensions, as yet unknown, of the ore bodies now being exploited.

It is easy to suggest that basic research in geology that would lead to an understanding of the origin of these ore deposits will lead us to new discoveries. It is much more difficult to predict the direction that will be taken by the applied research on techniques and instruments that are designed to locate the deposits in a tangible way. The past few years have seen the development of such new and effective tools as the airborne magnetometer and scintillometer, and such new techniques as those of geophysical and geochemical prospecting. The future will require devices that will permit the measurement of increasingly minute differences in the physical and chemical properties of rocks at increasingly great distances below the surface.

The second broad field of research probably will tend to be taken up somewhat later than the first, although it will overlap it and has already had work started in some areas. But emphasis on, and interest in, this field will in general be inversely proportional to the degree of success attained in finding for each commodity new ore bodies of present-day quality.

The attractiveness of a search for low-grade material stems from the early work of such men as Clarke and Washington (3) and of Goldschmidt (7) on

the abundance of elements in the earth's crust. Both of these studies yielded estimates of the percentage of each of the then-known elements.

Even a hundred-thousandth of a percent of an element, if applied to the volume of the crust, amounts to a staggering amount of material—more of practically every element than we can reasonably expect to need for many years into the future. And there is a considerable amount of empirical evidence that indicates that these average amounts are not uniformly distributed through the crust but are subject to varying degrees of concentration; some writers, in fact, suggest an approach to an inverse geometric relationship between tonnage and grade.

This reciprocal relationship between amount and quality or concentration, whether it follows some mathematical ratio or not, may well be true for practically every commodity. There is here a fertile field for investigation that can well lead to an increase of resource potential. Two sorts of problems will have to be solved in such an investigation. One concerns the exploration for deposits of these lower grade, or even trace, concentrations of particular commodities; and the other, the development of practical methods for beneficiating such material in order to secure a product that is useful or merchantable.

Research that will contribute to the exploration for such deposits may well take two related paths. One will be a systematic collection of analytical data to show the distribution of one or more elements or commodities in various types of geologic environments. Some work along this line was done during the last war at the instigation of C. K. Leith on behalf of the War Production Board (10). More comprehensive studies are currently under way at the Geological Survey and at the California Institute of Technology by Harrison Brown and his co-workers (2).

The other, and more fundamental, research objective would be to determine the principles that control the distribution of the elements in nature and the factors that cause their relative concentration in one environment and relative absence in another. To some degree, work along this line will be dependent upon the progress of data collection, but it will also require detailed knowledge of the earth's history and of the natural processes that have affected this history.

Starts have been made in this broad field by Goldschmidt (7a), Vernadsky (18), Fersman (4), Rankama and Sahama (15), and others; on specific elements by Lindgren (11), Fleischer (5, 6), and others; and on environmental factors (perhaps the most important phase) by Hutchinson (9) and Rubey (16). But a great deal of work remains to be done before we can predict with assurance where we may expect to find relative concentrations of needed commodities in amounts that will justify the research required to develop new recovery methods for such low-grade material.

The history of the mining industry certainly provides good grounds for believing that applied research on new methods of recovery of trace amounts of material will be successful if the need is apparent. The cyanide process and flotation are examples of techniques that greatly extended our ability to treat lower-grade ores. Ore with a content of 60 pounds of copper to the

ton was required 50 years ago, while today ore with only 12 pounds to the ton is being worked. It is likely that newer methods of recovery will be based to a large extent upon the necessity of reducing labor costs by increased mechanization, as this will be especially necessary to mine the large tonnage, low-grade deposits profitably. It is also probable that power costs must be lowered if these lower grade materials are to be workable.

Further we may reasonably expect that emphasis will be given to methods which will permit successive reductions in the amount of ore to be treated, together with processes that permit regeneration of the reagents. A much wider application in mineral resource beneficiation of one or another of the relatively new chromatography techniques is especially likely to be rewarding.

It is pertinent, in reviewing this potential field of research, to consider some of the areas in which the results obtained might be applied. The lowering of grade of workable copper ores has been noted; an even more significant (though mathematically less impressive) lowering appears to be close to achievement in iron ore as a result of the development of methods for treating the highly siliceous and low-grade taconites. Our resource potential in a number of other commodities may be expected to be similarly increased when and if the combination of economic reward in the form of higher prices and improved technology can be achieved.

There is another area in which research on trace element concentrations may be of importance. This is the recovery of minor amounts of elements as a by-product of other commodities. Trace amounts of molybdenum, for example, were long unrecognized in, or not recovered from, the large copper deposits, but they now provide a significant portion of our domestic production of this element.

The Atomic Energy Commission has recently announced (1) that small amounts of uranium, two-tenths to four-tenths of a pound per ton, are present in and can be recovered from the Florida phosphate deposits. Attention has recently been directed to trace amounts of the much needed niobium (columbium) in the Arkansas bauxite deposits (8) and germanium in certain coal beds (17). Applied research to recover both of these elements is actively under way.

A field in which research on trace element distribution may eventually be spectacularly successful is that in which a whole rock formation is mined and treated for a number of elements, few or none of which are present in anything like presently commercial amounts. The Phosphoria formation of the Rocky Mountain Region is such a unit; it includes, as separate beds, most of the high-grade phosphate rock in the western United States; and, in addition, it contains significant trace amounts of a number of metals, including uranium, vanadium, the rare earths, silver, nickel, zinc, and molybdenum, as well as appreciable quantities of fluorine, distillable hydrocarbons, and sulphur. McKelvey and his co-workers (12) have estimated that the formation is present over a large part of a 135,000-square-mile region. Within this area, the formation contains 1.7×10^{12}, or 1.7 trillion, metric tons of phosphate. In recent years a great deal has been learned about the distribution and amount of the trace elements in the formation and the relationship of each of them to

the major rock-forming units, such as the clay minerals, the phosphate minerals, the chert, and the carbonates. Much remains to be done, however, before we can define with any degree of precision the target that is offered by the Phosphoria, but on the basis of present knowledge, a thickness of 50 feet or more of rock, extending over several hundreds of square miles, may contain more than a half dozen commodities with a gross value of something in the order of $5 a ton. This may be an attractive target for our research scientists and technologists in the not too distant future.

There are other phosphate-containing formations in other parts of the world that seem to be similarly endowed with minor constituents, and scantier evidence suggests that other sedimentary rocks, especially in coal-bearing formations, and even igneous rocks may yield a group of products if economic methods can be developed to treat them in bulk.

The third broad field of research, that of providing substitute materials, is one that may be most succesfully attacked by a study of the fundamental physical and chemical properties of the basic components of our raw material supply, whether they are renewable or nonrenewable. In the long run, it seems to me to be sounder to search for materials that are in abundant supply and that have a particular combination of properties meeting specific needs rather than to think in terms of substitutions of magnesium for aluminum or plastics for steel, especially where such a need has in the past been met by a substance in currently short supply. It may even be possible that, with sufficient knowledge, future scientists and engineers may actually invent or create out of abundant materials new substances that have predictable, specific desired properties.

Better utilization of resources has commonly been cited as another appropriate field for research. It would seem, however, that improved utilization, like substitution, should be very largely controlled by a better knowledge of the physical and chemical properties of materials. Utilization, as such, will be most likely improved by better education of the consumer, and this is a research problem for the social scientist rather than the technologist.

In summary, it does not seem too improbable that, through one or another of the methods of improved exploration techniques, exploitation of presently unavailable supplies, or programs of substitution and improved utilization, raw materials for our civilization can be obtained for a long period in the future—entirely aside from the assurance provided by the constantly increasing supply provided by scrap or reuse materials.

This happy situation can be attained, however, only by maintaining a suitable economic environment to attract the participation of all elements of our civilization on the one hand and, on the other, by maintaining a supply of competent and well-trained scientists and engineers in the necessary fields of research. The economic climate will probably be forced upon us by the law of supply and demand; provision of an adequate supply of research men, however, will not be attained without careful advance planning and appropriate action to make the field attractive.

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GEOLOGIC STRUCTURES SURROUNDING THE SANTA RITA INTRUSIVE, NEW MEXICO

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ABSTRACT

The Silver City-Santa Rita region, in which are exposed rocks of early Tertiary age and older, is located within a block bounded by the northwest trending Mimbres and Silver City faults.

The Santa Rita granodiorite intrusive is about 6,200 feet long in a northwesterly direction, and averages 2,600 feet in width. It is flanked on its east and west sides by limbs of a south-plunging anticline. The granodiorite-sediment contact is nearly vertical over a good part of the east and west sides of the intrusive and plunges to the north at an angle of about 40 degrees. The anticlinal structure extends to the north where superimposed upon it are found at least three smaller flexures, domes and anticlines; zinc ore bodies are found in the upper portion of these structural highs.

There are no indications to date that the intrusive has a bottom. Its emplacement seems to have been a passive one followed by a downward readjustment in the north end of the mass. Other than an uplift of the sediments to form the anticline, there are no indications that the intrusive pushed or thrust the sediments aside such as the pushing or thrusting that apparently accompanied the Fierro-Hanover and Copper Flat intrusives.

It is conceivable that this difference in the mode of intrusion may account in part for the shattering of the rocks, which was so important for the formation of the copper ore bodies in the Santa Rita intrusive and is lacking in the Fierro-Hanover and Copper Flat intrusives.

INTRODUCTION

A BRIEF study of the geologic map of the southwestern part of the state of New Mexico, shows that the grain of the pre-Tertiary geology, which in Dona Ana, Socorro, Sierra and part of Luna counties has a predominantly north-south strike, assumes a complicated pattern within a block bounded by northwest trending fault systems in Grant County. This contrast becomes evident after a short examination of the pre-Tertiary geologic pattern in the Silver City, Pinos Altos, Central, Fierro-Hanover, and Santa Rita areas within the fault-bounded block and the simpler pattern of geologic structures in the pre-Tertiary rocks of adjoining areas. Such areas are the crest and east slope of the Mimbres Mountains, the Sierra Caballos, the Fra Cristobal Range and the San Adres Mountains.

Figure 1 shows the generalized geology in the fault-bounded block and its surrounding regions. On this map an attempt has been made to compile all the known geologic features in the area and due credit is here given to N. H.

Darton (2), Sidney Paige (8), A. C. Spencer (10), S. G. Lasky (6), G. J. Ballmer (1), and to the authors of the New Mexico Geological Society Guidebook, Fourth Field Conference, 1953 (11).

The fault that forms the northeast border of the block, known as the Mimbres Fault, is observed around the now abandoned Georgetown Mining District, and northwest of it for a distance of about eight or nine miles. Its southeastern extension has been traced by W. E. Elston (3), who states that the fault zone probably joins with the main northwest break in the Cooks Mountain Range, giving it a total known length of about thirty-five miles.

The fault on the southwest side of the block, which we propose to call the Silver City fault, is exposed only in its northwestern extremity, in the area northwest of Silver City, but is believed to extend to the southeast as shown. The evidence for this belief is based on information obtained in drilling for water in the alluvial fill south of Lone Mountain and Hurley, and is sufficient, in the opinion of the writers, to indicate the presence of a strong fault zone striking southeast approximately in the position shown in Figure 1.

Within the block, partly covered by volcanic rocks of Tertiary age, an area elongated in an east-west direction exposes the pre-Tertiary geology. This area may be called the "Silver City-Santa Rita window." It is bounded on its ends by the two parallel fault systems described above, and on the remaining sides by Tertiary volcanics or younger alluvials.

Since the days of the Spanish explorers certain parts of the Silver City-Santa Rita region have been known for their mineral wealth. The mineral occurrences which are well distributed within the window are known to have attracted the attention of prospectors since the earliest history of mining in the west and have developed into mining centers of economic importance. Mining activities have taken place at Chloride Flats, Silver City, Pinos Altos, Copper Flat, Lone Mountain, Fierro-Hanover, Bayard, Central, Santa Rita and Georgetown. These areas have produced a variety of metals including: copper, zinc, lead, silver, and gold, as well as minor amounts of manganese and iron.

The Bayard, Santa Rita and Fierro-Hanover areas have been the most productive centers of mining within the window, maintaining a position of seventh or higher in the national standing of zinc-producing districts for the last 15 years. The copper production from the disseminated deposit at Santa Rita is by far the most outstanding contribution of the window and this production has placed Santa Rita among the five largest copper-producing mines in the United States for the last 13 years.

GENERAL GEOLOGY OF THE SILVER CITY-SANTA RITA WINDOW

The principal geologic feature (first described by Sidney Paige (8) in 1916) in the pre-Tertiary rocks within the Silver City-Santa Rita window is a northwesterly trending syncline modified by numerous faults and by superimposed domal and anticlinal structures apparently related to the intrusive action of igneous bodies that crop out within the region. The width of the syncline, which extends from the Silver City fault to the Mimbres fault, is

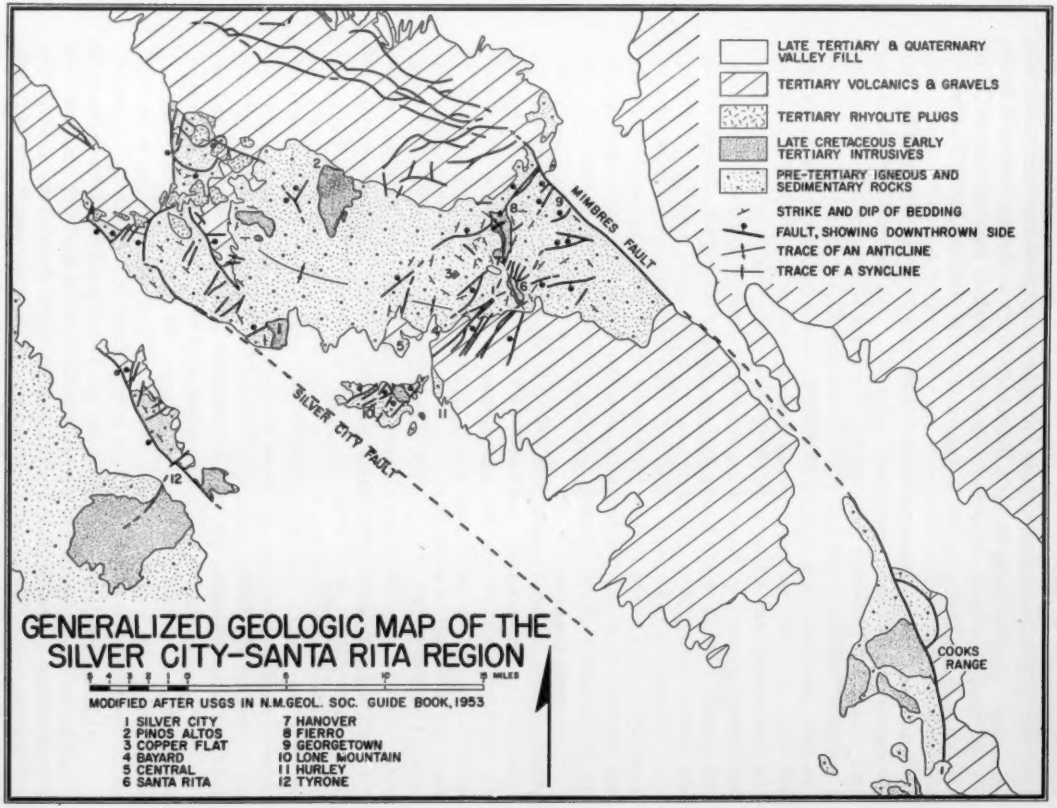
LATE TERTIARY & QUATERNARY VALLEY FILL
TERTIARY VOLCANICS & GRAVELS
TERTIARY RHYOLITE PLUGS
LATE CRETACEOUS EARLY TERTIARY INTRUSIVES
PRE-TERTIARY IGNEOUS AND SEDIMENTARY ROCKS
STRIKE AND DIP OF BEDDING
FAULT, SHOWING DOWNTHROWN SIDE
TRACE OF AN ANTICLINE
TRACE OF A SYNCLINE
MIMBRES FAULT
SILVER CITY FAULT
COOKS RANGE
GENERALIZED GEOLOGIC MAP OF THE SILVER CITY-SANTA RITA REGION
MILES
MODIFIED AFTER USGS IN N.M.GEOL. SOC. GUIDE BOOK, 1953
1 SILVER CITY
2 PINOS ALTOS
3 COPPER FLAT
4 BAYARD
5 CENTRAL
6 SANTA RITA
7 HANOVER
8 FIERRO
9 GEORGETOWN
10 LONE MOUNTAIN
11 HURLEY
12 TYRONE

FIG. 1.

approximately 16 miles and the depth of the trough seems to be of the order of 1,500 feet.

The synclinal structure is well indicated by its southwestward and northeastward dipping limbs of early Paleozoic rocks in Georgetown and in the Lone Mountain area, respectively, and its trough is partially known in the underground workings in the Bayard area of the Central Mining District.

SEQUENCE OF GEOLOGIC UNITS IN THE SILVER CITY—SANTA RITA REGION

Age	Formation	Thickness (feet)
Quaternary	Alluvium	
	Unconformity	
Tertiary	Conglomerate (Mimbres)	0–1,500+
	Unconformity	
	Basalt, andesite flows	
	Latite, rhyolite tuffs	0–±2,500
	Unconformity	
Upper Cretaceous	Volcanic breccia	
	Unconformity	
	Colorado formation	±900–2675
	Beartooth Qtzite	50–140
	Unconformity	
Permian	Abo formation	0–200
Pennsylvania	Magdalena group	±700–1300
	Unconformity	
Mississippian	Lake Valley	40–400
Upper Devonian	Percha shale	200–315
	Unconformity	
Silurian and Upper Ordovician	Fusselman limestone and Montoya limestone	500±
Lower Ordovician	El Paso limestone	500±
Cambrian	Bliss formation	145±
	Unconformity	
Precambrian		

Although the faults that bound the pre-Tertiary window both strike to the northwest, a large number of the main faults inside of the block bear northeast. This is illustrated by the trend of the main breaks in the vicinity of Silver City, Lone Mountain, Bayard and Georgetown, which strike nearly at right angles to the bounding faults. Certain localities, however, notably Santa Rita and Hanover, show a prominent north-south trend in the strike of the main faulting.

The general geology and stratigraphy of the region have been described in detail before (8, 2, 10, 7, 6). For the present purpose we will describe briefly the formations found within the window and make a brief summary of that part of its geologic history related to intrusive activity.

The stratigraphic section is composed largely of Paleozoic limestones divided by the Percha Shale of Devonian age into the so-called upper and lower limestones. The lower limestones are of Silurian and Ordovician ages and are generally dolomitic, locally sandy and rest conformably upon the Bliss sandstone of Cambrian age. The upper limestones, of Carboniferous age, are generally fossiliferous and contain numerous shale and shaly horizons. Two notable members of the Carboniferous rocks are the Crinoidal limestone, a pure, coarsely crystalline limestone, and the Parting shale; the latter rests unconformably upon the former, and serves as a marker horizon. The Abo redbeds of Permian age are present only locally within the window and terminate the Paleozoic system. There are no Triassic, or Jurassic rocks found in the region. Upper Cretaceous sandstones and shales of the Colorado formation constitute a large portion of the remaining sedimentary section and rest conformably upon the Beartooth quartzite (lower (?) Cretaceous). Cretaceous volcanic rocks are locally present particularly in the Pinos Altos area. Tuffs, tuffaceous sandstones, volcanic rocks and gravels all of Tertiary age, and Quartenary gravels, alluvium, and talus make up the remainder of the section.

The region shows evidence of a period of intense intrusive activity during a part of its geologic history. The oldest post Precambrian igneous rocks known are probably of late Cretaceous age and are described by Paige (8, p. 7) as "rocks of the diorite-andesite group, comprising also volcanic breccias and perhaps some lava flows. . . . Hundreds of dikes of the same sort form a veritable network cutting the Colorado shale. . . ." W. R. Jones (4), after recent studies in the region, describes them in much the same manner. They are found principally in the Pinos Altos Mountains northeast of Silver City, and in an area on the north side of the Barringer Fault, northwest of Fierro.

The next youngest igneous rocks are sills and laccoliths, quartz diorites, that intruded the sedimentary series, probably in late Cretaceous time, apparently before extensive faulting had broken the sediments. There followed another series of sills also of dioritic composition whose age relative to the earlier sills was determined (6, p. 26, 27) on the basis of the cross-cutting relationship of a dike of one type rock into a sill of the other.

The thickness of these sills, sheets and laccoliths, varies from a few tens of feet to as much as 600 or 700 feet and they have raised the intruded sedimentary formations into gentle domes that now appear superimposed on the broad regional syncline.

Faulting with a north to N40°E strike occurred on a large scale after the formation of the sills and this faulting established the planes of weakness along parts of which were emplaced a number of dikes of granodioritic composition.

The next event in the intrusive history of the region, probably still in late Cretaceous time, was the emplacement of the large granodiorite bodies, which in some cases uplifted the intruded sediments, and in others steeply folded

them or pushed them aside. The sediments on the east and west contacts of the Fierro-Hanover intrusive, for example, dip steeply away from it and H. C. Schmitt (9) says that, "the intrusive has thrust aside its walls." The Copper Flat intrusive, according to Lasky and Hoagland (7), has pushed the beds that encircle the mass into a series of en echelon anticlines and synclines that are in part overturned. The attitude of the sedimentary rocks around the Santa Rita intrusive is that of an anticline whose axial plane more or less coincides with the long axis of the intrusive. Here, there is no evidence that the beds have been thrust or pushed aside.

Additional north to northeast faulting, and the probable reopening and recurrence of movement along some of the earlier faults, took place in early Tertiary time after the emplacement of the granodiorite intrusives. Some of these new fissures were filled by dikes, this time of quartz monzonite. From this time on to about the middle of the Tertiary the geologic history of the region is characterized by continued faulting, intrusion of latite and rhyolite plugs, and the introduction of dikes along some of the earlier faults as well as along some of the new ones. The repeated opening of pre-existing breaks is shown by the occurrence of composite dikes in which a quartz monzonite or even a granodiorite dike is flanked on one or both sides by latite dikes. The presence of faults following along and crosscutting these composite dikes is evidence of repeated later movements.

The final phase of the igneous history of the area consisted of outpourings of lavas and deposition of pyroclastic materials of Tertiary age. These volcanic rocks are very conspicuous, particularly in a part of the southern boundary of the Silver City-Santa Rita window, where they form a prominent scarp. There is some evidence that the now exposed older rocks of the region were once covered by these volcanic products. This possibility is open to question, however, and it is not our purpose to weigh or even present the related data. Evidence of post-lava faulting is very distinct. That some post-lava movement was localized along pre-existing faults is obvious, particularly in the Ground Hog mine where pre- and post-lava displacements can be observed (6, p. 49–55, 106–116).

THE SANTA RITA AREA

The Santa Rita area has long been known for its copper production. Ores of this metal have been produced on a large scale from the Chino open pit mine since 1911 with only minor interruptions. Zinc ores also have been mined from the area for the last quarter century. The most striking feature of the area is the disseminated copper mineralization with its associated fracturing and alteration. Secondary chalcocite occurs in the granodiorite intrusive and in the nearby sediments, particularly where the rocks are most intricately fractured.

On the outer edges of the intrusive, in the limestone formations, there is a pronounced zone of contact metasomatism. This halo is known best in the northern half of the Santa Rita area where it is very conspicuous, consisting of abundant magnetite, lesser amounts of garnet, epidote, chlorite, pyrite, and

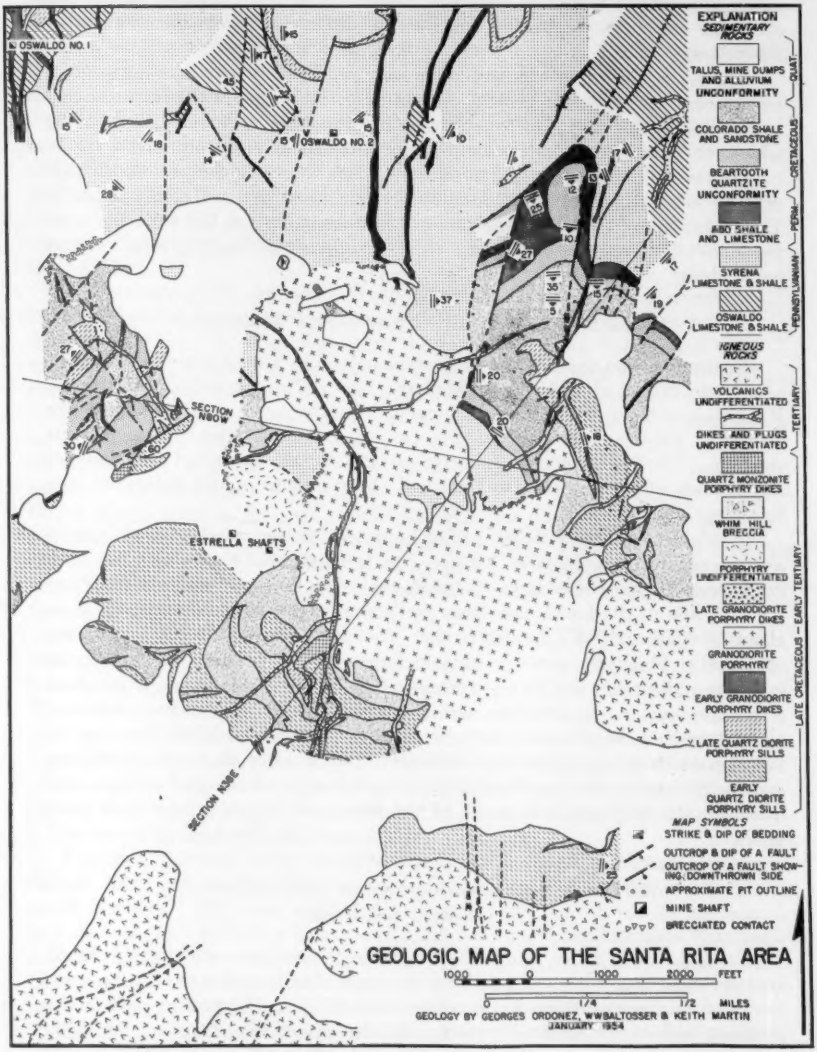

FIG. 2. Geological map of the Santa Rita area (carbonate fault just below the s of "section" in left center).

minor amounts of pyrrhotite, chalcopyrite and sphalerite. Outside and in this zone are the zinc ore bodies which occur as replacement deposits in the limestones.

The configuration of the magnetite zone and in places its fringing zone of zinc mineral deposition is broadly controlled by the shape of the intrusive and is modified by bedding planes, permeable horizons, and faults and dikes, along which there has been greater migration of the mineralizing solutions.

Zinc ore bodies are associated with structural highs in the sediments, particularly where these are intersected by pre-mineral structures, dikes, or faults. The Crinoidal or Hanover Limestone of Mississippian age has been the most productive horizon, presumably by virtue of its outstandingly greater relative permeability.

GEOLOGIC STRUCTURE IN THE SANTA RITA AREA

Figure 2 shows the geology of an area of nearly 5 square miles in the approximate center of which is located the Santa Rita granodiorite intrusive. Roughly one-third of the area is covered by mine dumps and talus and the contact of the intrusive with the surrounding sediments cannot be seen in its entirety. There are enough data available, however, to permit the study of the attitude of the intrusive contact and the structure of the sediments surrounding it.

Careful observation of the geologic pattern shown by Figure 2 reveals several conspicuous features. First, the intrusive body is elongated in a northwest-southeast direction. Second, there are two predominant trends in the direction of the faults and dikes that traverse the area, one striking from about N10°W to N40°E, and the other from approximately N60°E to nearly east-west. Third, the pattern of the sedimentary formations surrounding the intrusive indicate an anticlinal structure (Fig. 3), the trace of the axial plane of which more or less coincides with the long axis of the intrusive. The exposed length of the intrusive along its major axis is about 6,200 feet, and its average width is approximately 2,600 feet. Rock outcrops to the northwest and to the southeast along the main axis are concealed by mine dumps, and therefore the total exposed length of the intrusive originally may have been greater.

Attitude of the Instrusive Contact and Structure of Surrounding Sediments

Drilling to a depth of about 800 feet below the surface surrounding the pit area indicates that the contact between the granodiorite intrusive and the limestones of the Syrena formation is nearly vertical along the greater part of the northern half of the eastern contact. To the east of the intrusion the sediments dip eastward, away from the intrusive, at angles varying between 20 and 30 degrees, forming the east limb of a fold. The contact of the Colorado formation with the intrusive is also vertical to approximately the same depth on the southwest side of the intrusive. Southwest of the intrusive the sedi-

ments dip to the southwest, away from it, at angles between 15 to 20 degrees, thus forming a part of the western limb of the anticlinal structure.

The western contact of the granodiorite intrusive east of the Estrella shafts is obscured by intense alteration of the rocks that has almost completely destroyed their original character. This area is roughly 800 feet in an east-west direction by 1,600 feet north-south. It extends east from the foot of the dump area on which the Estrella shafts are located, and is shown on the map as undifferentiated porphyry. At present it is uncertain whether the unidentified rock is an early quartz diorite sill or a part of the granodiorite of the intrusive. The evidence is inconclusive at the moment, and the structure in this small portion of the western contact must remain in doubt until the rocks can be identified.

The attitude of the sediments along the northern third of the western contact is somewhat complicated, and for a short distance does not conform with the anticlinal limb dipping away from the intrusive. The Syrena and Colorado sediments, exposed in vertical contact with the granodiorite in the western constriction of the intrusive, bear northeast, dip northwest and therefore strike into the intrusive instead of paralleling it. This exposure is bounded on the north by the Carbonate fault, a south-dipping normal fault striking about N60°W, which places the Colorado in contact with the Syrena formation—a displacement that may be three hundred feet or slightly more. North of this fault, in the area around Lee Hill, the faulted and repeated section of Colorado sediments and accompanying late diorite sill still strike northeast and dip northwest. Within a distance of six or eight hundred feet to the north the beds swing and resume the northwest strike and southwestern dip, thus forming again the western limb of the anticline.

On the north side of the Chino pit, just at the edge of the dump area, a thin shell of extremely altered Syrena formation, to all appearances nearly horizontal, appears to cover the intrusive as if forming a thin roof over it. The presence of magnetite in other exposures in this area strongly indicates that the intrusive may extend to the northwest under the Syrena, which, resting nearly horizontally over it, forms the flat crest of the northern extension of the anticlinal structure. Furthermore, drill hole data show that the upper part of the intrusive dips to the northwest at an angle of about 40 degrees for a distance of at least 600 feet from the last exposure.

Farther northwest of the intrusive the broad anticlinal structure persists, though there are smaller flexures superimposed upon it. West of the Oswaldo Number 1 Shaft the bedding dips westerly and constitutes the northern extension of the western limb, whereas 2,000 feet east of the Oswaldo Number 2 Shaft the beds dip east, forming the northern extension of the eastern limb. Between these outer flanks there are at least three small structural highs in the form of elongated anticlines or domes superimposed on the structure.

Still farther to the northwest the deformation effects lose the features associated with the Santa Rita intrusive and mingle with those of the Hanover intrusive.

The southeastern contact of the intrusive is completely buried by mine dumps and talus that obscure its location and other details. Drilling has en-

countered the granodiorite at a distance of about 500 feet to the southeast of the pit perimeter. Kerr (5), who visited old underground workings (now caved) still farther to the southeast, suggests that the granodiorite intrusive may extend nearly one thousand feet in that direction.

Rock exposures and drill hole data southeast of the pit perimeter indicate the possible presence of an anticline, which could be the southeastern extension of the structure flanking the intrusive. The same drill data indicate that the anticline pitches to the southeast at a gradient of about 600 feet to the mile.

We have said that the Santa Rita intrusive has nearly vertical contacts along much of its east and west sides. Its northwestern nose plunges about 40 degrees northwest and there may be a similar nose to the southeast. It is important to note that there are no indications that the intrusive body has a floor or partial floor such as the one in the south end of the Hanover intrusive (7, 9). Neither are there indications of a partial floor and dike-like or chimney-like roots, such as those in the Copper Flat intrusive (7).

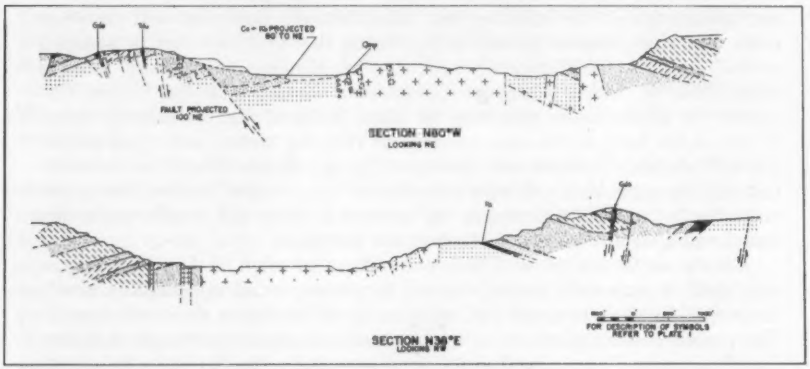

FIG. 3. Sections across Santa Rita area.

Furthermore, other than an uplift of the sediments to form the anticlinal structure previously described, there are no indications that the Santa Rita intrusive pushed or thrust the sediments aside, such as that which seems to have accompanied the emplacement of the Copper Flat (7) intrusive, or the thrusting at the southern part of the Fierro-Hanover intrusive (9, p. 73–75).

Quartz Diorite Sills

Sills of early and late quartz diorite (late Cretaceous) occur in the Colorado formation in the Santa Rita area. Their most obvious characteristic is an increase in their aggregate thickness toward the southwest. Their aggregate thickness of about 450 feet in two sills on the east flank of the anticline is considerably less than that on the west flank where it is about 950 feet in four sills. The decrease in thickness toward the northeast is very evident in the northeastern part of the area, where the sill of early quartz diorite, which

is 350 feet thick on the pit benches, disappears within a distance of 1,400 feet. Section A-B (Fig. 3) drawn along a line N38°E shows clearly the thickening of the sills to the southwest. This thickening continues southwest beyond the Santa Rita area to the Bayard area where the total thickness of all sills attains a possible maximum of 1,675 feet.

Faults and Dikes

The pattern of faults and dikes in the Santa Rita area differs from that of other areas in the Silver City-Santa Rita window. For example, whereas a strong northeasterly strike predominates in the main faulting in the Bayard, Silver City and Georgetown areas, we can distinguish two major systems in the Santa Rita area: one striking from a few degrees northwest to about N40°E with many representatives, and the other one striking from N60°E to nearly east-west with few representatives. For simplicity we will hereafter designate the former as the north-south system and latter as the east-west system.

There is a notable difference in the intensity and direction of faulting in various parts of the Santa Rita area. North-south faults and dikes are abundant in the northern third whereas they seem to be less numerous in the southern third. The center portion is characterized by the presence of the main east-west faults and by the relative absence of north-south ones. Consequently these three parts of the area will be discussed separately.

Northern Part.—North-south faults and dikes are prominent and numerous whereas east-west faults are represented by one or two minor breaks in the northeast corner of the area. The granodiorite-type dikes—the oldest known in the area—are the most prominent and generally occupy north-south faults. This association leads to the suggestion that north-south faults predominated in late Cretaceous time, prior to the emplacement of the granodiorite intrusive. Zinc ores have been mined from this part of the Santa Rita area along these structures; their importance from the standpoint of exploration for zinc deposits is well recognized.

The displacement along north-south faults is mostly normal and, with the possible exception of a few minor slips, there are no known reverse faults. The most striking feature of the north-south faulting is that westward dips are more common in the eastern portion and the opposite in the western part. The net result of the movements along these faults is that the formations have been dropped in the center, relative to the eastern and western parts. This graben includes the north end of the intrusive and the area surrounding its northern nose. In other words, it seems as if the emplacement of the Santa Rita intrusive was followed by a downward readjustment toward the intrusive itself, in the northern part at least. This graben normally should result in the exposure of the younger formations within the sunken block, and the oldest outside it, yet the opposite is true. The reason for this is that prior to the formation of the graben the intrusive had folded the sediments upward to an elevation such that the older formations are now exposed inside the graben where the younger beds should be.

Southern Part.—Our knowledge of faulting in the southern third is less than in the northern third because mine dumps cover bedrock exposures, and also because of a lack of underground workings. In the areas of exposed bedrock faults are not as abundant as in the northern third, and there is the possibility that this portion of the area is not as intensely faulted as its northern counterpart. The lack of serious interruptions and disruptions in the exposures of the sills and Colorado sediments in the southwestern part of the pit lend support to this idea.

North-south faults are more abundant than east-west faults; only one or two weak east-west faults occur in the western sector. There are no indications known to indicate a sunken area or graben such as that found north of the intrusive.

To date only three sizable dikes are known in the southern part of the Santa Rita area. Each one of these represents one of the three types—namely, granodioritic, quartz monzonitic, and latitic.

Center Part.—This sector is characterized by the presence of the two most prominent east-west faults in the Santa Rita area and by a scarcity of north-south dikes and faults.

The main east-west fault is the Carbonate fault, which we have said drops the Colorado sediments on the south a distance of about 300 feet. The other east-west structure, with little or no apparent displacement, is known mainly because it is occupied by a dike of latite over part of its known strike length.

The Carbonate fault, which is so conspicuous west of the intrusive, is not recognized east of it. It discloses post-granodiorite movement as indicated by displacement of the western contact of the intrusive. Like other faults in the area it cannot be traced across the granodiorite.

CONCLUSIONS

The possible relationship of the main structural features to the mineral deposits may now be considered.

The zinc deposits developed to date are in the northern and northwestern part of the area and occur mostly as replacement bodies in certain favorable limestone beds. Detailed geologic mapping has shown that these deposits are localized along highs within the broad anticline, which is the northern extension of the structure flanking the intrusive. Synclinal troughs within the anticline are generally barren or only weakly mineralized, and even at the apparently favorable intersection of north-south dikes or faults with the Crinoidal Limestone, ore may not occur unless their intersection lies in the upper portion of a structural high. Deformation of the beds had a noticeable influence on the localization of zinc ore.

Development and exploration in the Santa Rita pit to date disclose the fact that, with but one minor exception, the disseminated ore bodies of supergene chalcocite occur along the intrusive contact, in the granodiorite, and/or in the sediments and sills. These ore bodies are elongated in a northwesterly direction showing remarkable parallelism to the long axis of the intrusive and a relationship is indicated between the shape of the granodiorite intrusive and the copper ore accumulations.

The structural differences among the three economically important intrusives in the Silver City-Santa Rita window may be restated. The three are Fierro-Hanover, Copper Flat, and Santa Rita. The first two seem to have floors, at least partial, and their emplacement seems to have been a forceful one that pushed or thrust aside the surrounding sediments. Both of them have zinc ore bodies in at least part of their periphery.

The third one, namely, Santa Rita, does not appear to have a floor at least to a depth of 800 feet below the surface. Furthermore, the emplacement of the intrusive seems to have occurred with less force and was followed by a downward readjustment of the sedimentary beds, at least in the area surrounding the northern part of the intrusive. Zinc ore deposits also occur around this intrusive, but in addition disseminated copper mineralization is found associated with the shattering of the intrusive, and of the sediments and sills surrounding it.

It is conceivable that the difference in the mode of intrusion may account partly for the presence of the shattering of the rocks, which was so important for the formation of the copper ore bodies in Santa Rita, and is lacking in the other two. We are not proposing the theory that shattering of an intrusive body must necessarily accompany a passive intrusive, but we do state that a contrast exists between the mode of emplacement of the Fierro-Hanover and Copper Flat intrusives, as compared with that in Santa Rita, which may account in part for the difference in their internal structure.

The writers are indebted to Mr. W. H. Goodrich, General Manager of the Chino Mines Division of Kennecott Copper Corporation for permission to publish the data gathered in the Santa Rita area.

KENNECOTT COPPER CORP.,
NEW YORK, N. Y., AND SANTA RITA, NEW MEX.,
August 23, 1954

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VACUUM DIFFERENTIAL THERMAL ANALYSIS OF COAL

LEWIS H. KING AND WALTER L. WHITEHEAD

ABSTRACT

Samples of 25–30 mgs of various coals and their constituents were analyzed by vacuum differential thermal analysis using a heating rate of 20° C per minute. Exothermic and endothermic peaks obtained by this technique provide graphic representations of the net thermal effects from the physical and chemical changes that take place during carbonization. Replicate analyses show that both peak temperature and the area under a peak can be reproduced readily.

Thermograms of vitrains selected from a number of coals of widely different rank show an increase in peak temperature with increasing rank. Similar correlation is obtained between peak temperatures and fixed carbon values using vitrains from coals of the bituminous A group.

A study of samples of known petrographic composition reveals that neither exinite nor opaque matter exerts any evident control on the peak temperature. Peak temperatures of average samples of coal from different intervals in a column sample show no correlation with the percentages of fixed carbon. The peak temperatures are relatively constant for average samples taken from a given column sample, but the fixed carbon values show considerable spread. It is concluded that the fixed carbon of a vitrain provides a better index of rank than the fixed carbon of an average sample.

Further conclusions are that thermographic analysis is a useful method for the detection of cellulose in lignites and that the chemical fraction of the coal extractable with pyridine gives rise to the peaks. The suggestion is made that future investigators should consider the possibilities of relating the thermographic curves to the coking properties of coal.

INTRODUCTION

VACUUM differential thermal analysis has been employed by Whitehead and Breger (2, 9)[1] to study the structural relationships existing between cellulose, lignin and various coals by means of their thermal decomposition characteristics. Among other things, these studies showed that the various coal groups from lignite to semi-anthracite give exothermic peaks that are displaced to higher temperatures with increasing rank.

The present study was designed principally to establish a correlation between the fixed carbon content and exothermic peak temperatures using vitrains from within one group of coals: high-volatile bituminous A. Other phases of this investigation include work on various aspects of reproducibility, the effects of the macerals on the thermographic curves, and further work on the detection of cellulose in lignite.

[1] Numbers in parentheses refer to References at end of paper.

ACKNOWLEDGMENTS

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The authors are indebted to the following persons who generously provided samples for this investigation: Dr. P. A. Hacquebard of the Geological Survey of Canada; Dr. B. C. Parks of the U. S. Bureau of Mines; Drs. G. H. Cady and R. M. Kosanke of the Illinois Geological Survey; and Prof. E. S. Barghoorn of Harvard University. Dr. Hacquebard directed petrographic study of the coals. The authors are also grateful to Danford G. Kelley for a number of the thermal analyses and to M. Bates of the Dominion Steel Company, Glace Bay, Nova Scotia for the proximate analyses.

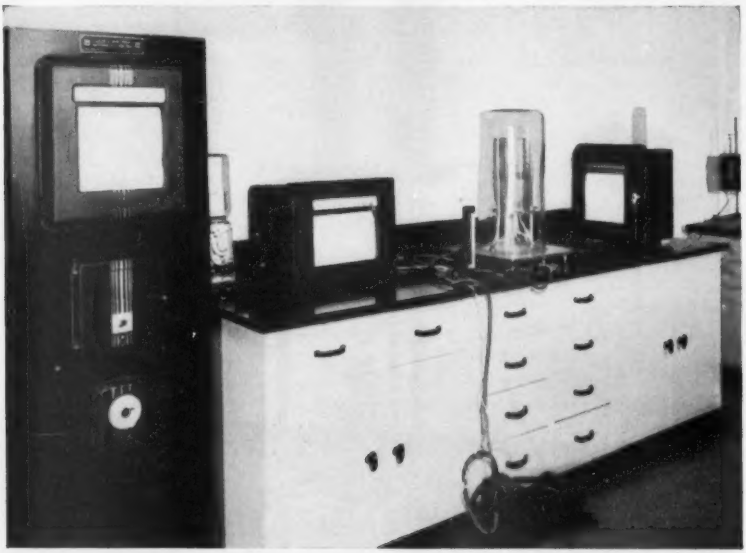

FIG. 1. Apparatus for thermographic analysis showing furnace, controller, recorders, galvanometer, time-switch, vacuum gauge and pump.

APPARATUS AND TECHNIQUE

The design of equipment for vacuum differential thermal analysis and the technique of operation have been described by Whitehead and Breger (2, 8). The technique followed during this investigation is essentially the same, excepting some slight modification by an increase in heating rate and a decrease in sample size.

Analyses were carried out by heating the samples to 700° C at a rate of 20° C per minute and recording the temperatures at which exothermic and endothermic reactions took place. A constant heating rate was obtained by

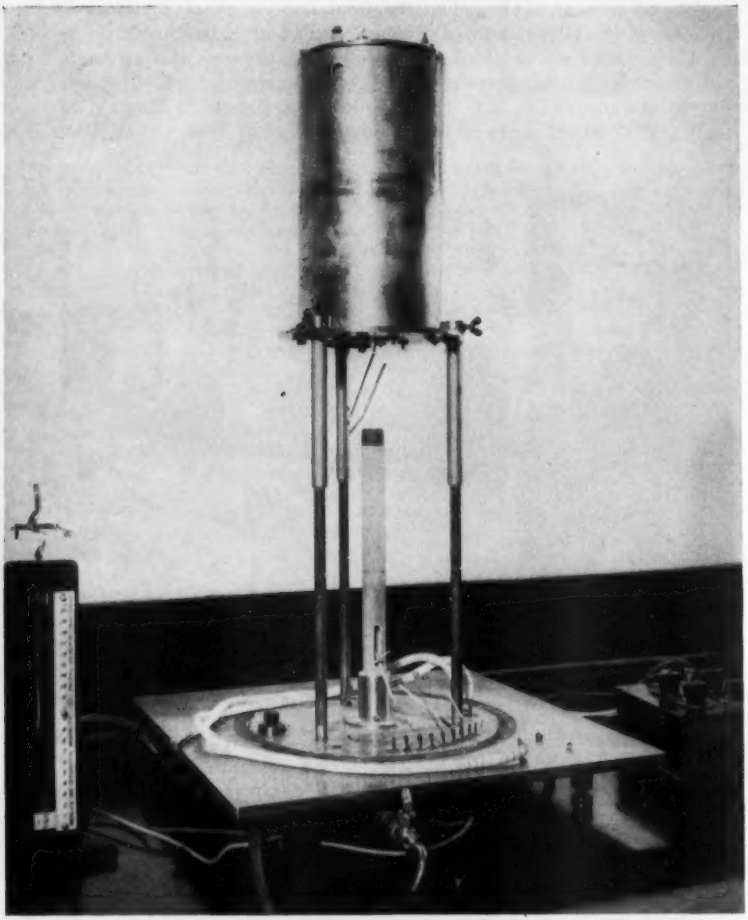

FIG. 2. Furnace in raised position for loading of specimen.

a Leeds and Northrup program controller and the sample record or thermogram was made by a Beckman photocell recorder (Fig. 1). The temperatures at which the peaks occur were measured by a Brown recorder. The furnace and sample block assembly are shown in greater detail in Figure 2. Here

the radiation-type furnace is viewed in its elevated position. The sample block is a solid steel cylinder containing two vertical holes or thermocouple wells and is supported on an Alundum post. The differential circuit consists of a two-headed thermocouple, one head being centered in each hole in the block. Samples, generally 25–30 mgs, are carefully packed around the head of one of these thermocouples, alumina occupying the remaining space in the well. The other thermocouple is completely surrounded with alumina containing 5 percent quartz. The quartz serves as an internal standard. Both sides are packed at a pressure of 530 pounds per square inch. All runs are carried out under vacuum with pressure less than 1 mm of mercury.

An optimum amount of sample was found necessary in order to obtain highly reproducible results. Sufficient sample must be used to produce a well defined peak, but greater quantities cause the sample to be partially ejected from the thermocouple well at some time during the formation of the peak. A detrimental endothermic effect is thus produced, which may occasionally be very slight and appear merely as a shoulder on the limb of the peak. Ejection of sample results from an increase of pressure caused by evolution of gas and by swelling of the coal. The difficulty has been overcome to some extent by securing the sample block cover with screws. Under these conditions the optimum amount of sample for high-volatile bituminous A coals is 25 or 30 mgs. Air dried samples were used throughout the investigation.

Exothermic and endothermic effects are recorded in empirical units. This procedure was used in studies of coal by the authors cited above, and has been customary in differential thermal analysis since the time of Le Chatelier. When adjustments are well made, the base line is a horizontal straight line, but seldom can be maintained throughout a run with that character. Careful runs were made with the apparatus to establish horizontal base lines with quartz or alumina of equal weight and packing in both holes in the sample blocks. Measurements of standard against standard in this way gave a zero base line, close to a horizontal straight line. Where alumina was used as sample and quartz as standard the base line deviated from the horizontal, although in the temperture range used neither material should show any thermal effect, other than changes in thermal conductivity and heat capacity. The departure from horizontality is interpreted as being caused by changes at differing rates in these physical properties of the two powdered materials as the temperature rises. Such an effect with coal is complicated by water-loss at low tempertures, seen in a bend of the base line towards endothermic.

EXPERIMENTAL RESULTS

The experimental work falls into three categories: (1) work of a general nature pertaining to a number of coals of different rank, (2) detection of cellulose in lignites, and (3) a somewhat detailed investigation of high-volatile bituminous A coals.

General.—The thermograms in Figure 3 represent vitrinite samples taken from a number of coals of varying rank. These curves show that the peak temperature increases with increasing rank. Vitrains from lignite, for ex-

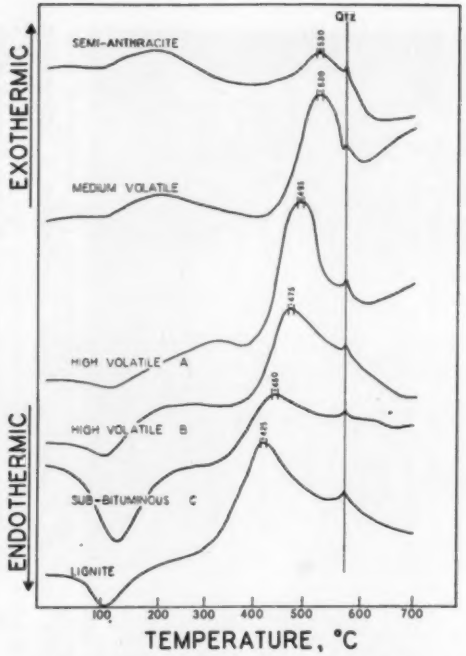

FIG. 3. Thermographic curves of vitrains from semi-anthracite from Pennsylvania; Medium volatile coal, U. S. Bureau of Mines; High Volatile A coal, Sydney, Nova Scotia; High volatile B coal, No. 6 coal bed, Franklin County, Illinois; Sub-bituminous C, Hanna Basin, Wyoming; Lignite, Brandon, Vermont.

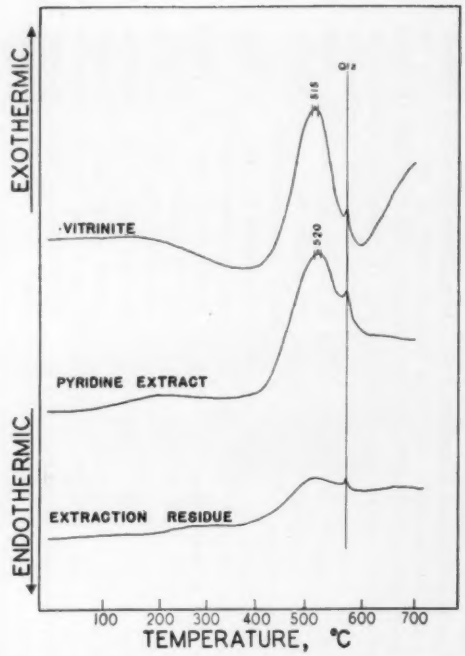

FIG. 4. Thermograms for a vitrinite, its pyridine extract, and the extraction residue. Vitrinite from the Pittsburgh coal seam, Pennsylvania.

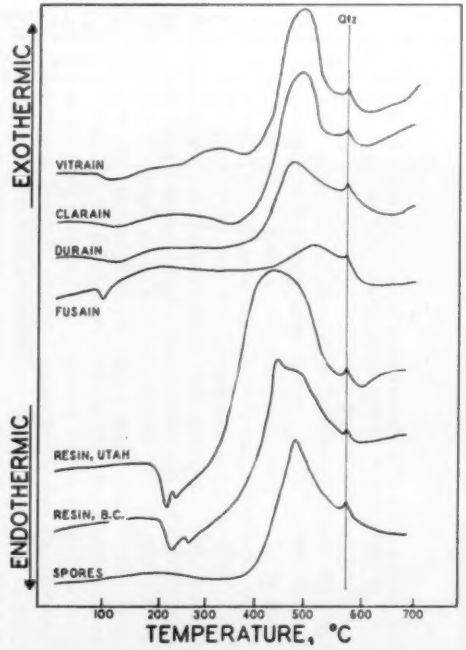

FIG. 5. Comparison of the thermal properties of vitrain, clarain, durain, fusain, resin and spores. Vitrain, clarain, durain, and fusain from Sydney, Nova Scotia; (high volatile A); Resins from Utah and British Columbia; Spores from U. S. Bureau of Mines.

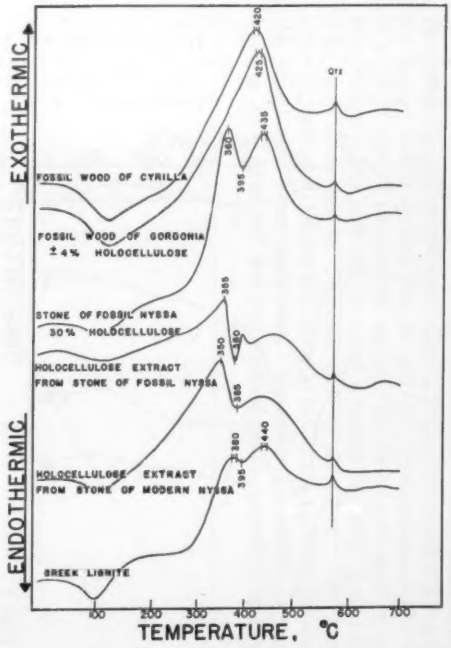

FIG. 6. Thermograms of lignites and holocellulose extracts from Brandon, Vermont, and Greece.

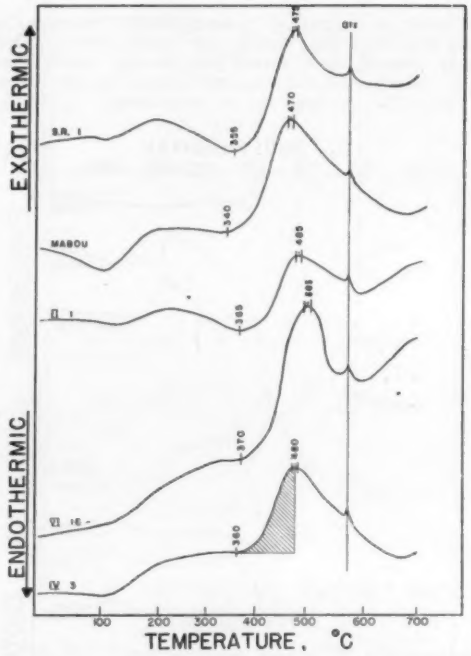

FIG. 7. Thermographic curves of composite vitrains (high volatile A) from Sydney, Mabou, and St. Rose, Nova Scotia. S. R. I., St. Rose seam No. 1; Mabou, 7 foot seam; II 1, Lloyd Cove seam; VI 16, Backpit seam; IV 3, Harbour seam.

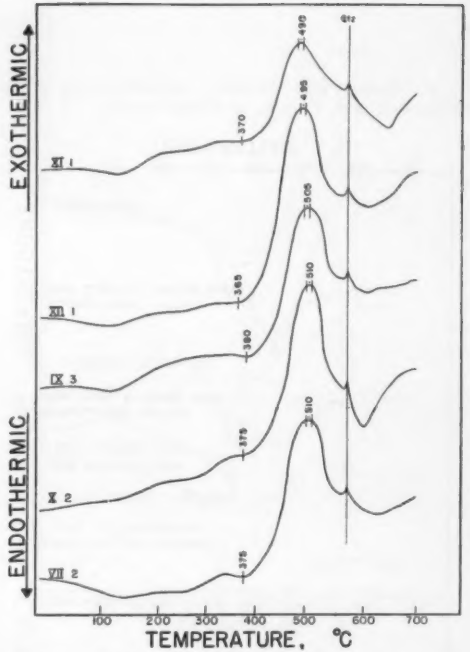

FIG. 8. Thermographic curves of composite vitrains (high volatile A) from Sydney, Nova Scotia. XI 1, Mullina seam; XII 1, Tracy seam; IX 3, Emery seam; X 2, Gardner seam; VII 2, Phalen seam.

ample, characteristically show peak temperatures of 420–430° C, while vitrains from bituminous A coals fall in the range 475–510° C. Data on many samples representing all ranks of coal would be necessary to determine whether the change in peak temperature with rank is a continuous relationship. From the meager data it appears that the sub-bituminous groups might be restricted to a rather limited temperature range. In the bituminous A group the temperature spread is sufficient to allow a correlation with fixed carbon values. This correlation will be discussed later in the paper. The semi-anthracite peaks are rather indefinite and seem to fall in the same temperature range as the higher rank bituminous coals. No curves for anthracite are illustrated, but they show even less definitely defined peaks than the semi-anthracites.

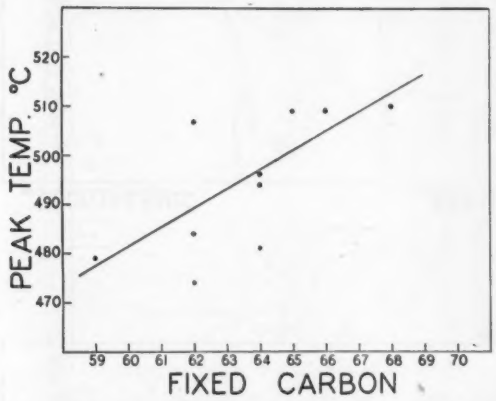

FIG. 9. Correlation of peak temperatures with fixed carbon contents for the ten vitrains illustrated in figures 7 and 8.

With the exception of semi-anthracite and anthracite, the height of a peak, or more explicitly the area under a peak, is not controlled by rank but is a peculiar property related to the individual sample. It is quite possible to obtain peaks of similar area from lignites and bituminous coals.

The fraction of the coal that decomposes and gives rise to the peaks is apparently in the material extractable with pyridine. The thermograms of Figure 4 are for a vitrinite, its pyridine extract, and the extraction residue. The vitrinite and extract show similar peaks at 515° C and 520° C. An equal quantity of the residue produces only a slight peak in the same temperature range. This fact would seem to indicate that the exothermic peaks obtained with various coals probably are produced by the extractable material.

The curves shown in Figure 5 compare the thermal decomposition of vitrain, clarain, durain, fusain, spores and resin. The curves for vitrain, clarain and durain are similar in their overall characteristics. Clarain and vitrain are indistinguishable while the thermographic peak for durain is somewhat

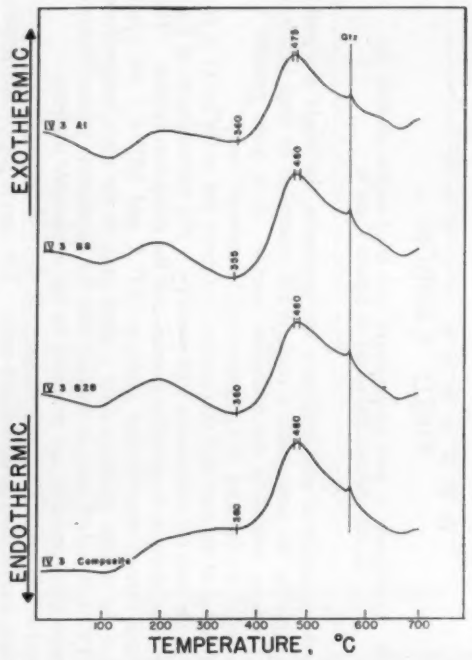

FIG. 10. Thermograms of different vitrain bands (high volatile A) from the same column: IV 3, Harbour seam, Sydney, Nova Scotia.

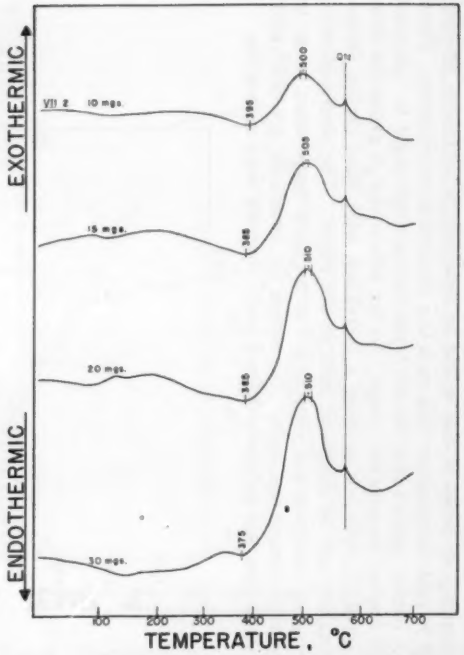

FIG. 11. Thermograms illustrating the effects produced by varying the sample size of a vitrain from VII 2, Phalen seam, Sydney, Nova Scotia (high volatile A).

smaller. Only one sample of spores has been examined thermographically. Its peak differs from those obtained from vitrain and clarain and is considerably sharper. The fusain is almost inert and shows only a gentle exothermic rise in the 500–530° C temperature range. This observation has been noted with other specimens of fusain containing up to 20 percent of volatile matter. The two resins examined are unique in that they show two small endothermic peaks between 200° C and 275° C, and very broad exothermic peaks.

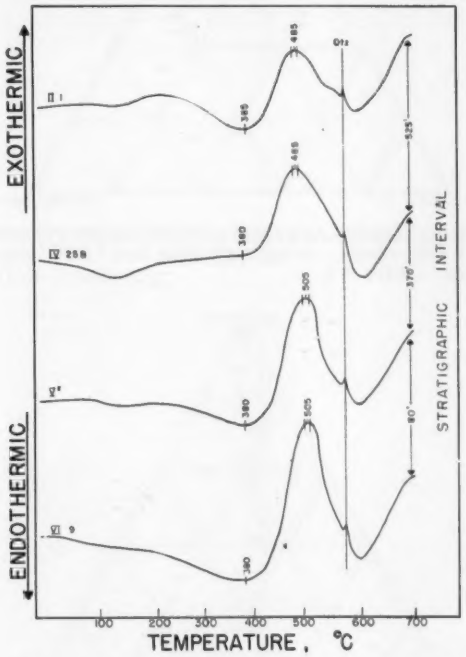

FIG. 12. Thermograms of composite vitrains (high volatile A) illustrating the relationship between peak temperature and depth of burial. Samples are from drillhole No. 18 in the Sydney Field. II 1, Lloyd Cove seam; IV 25B, Harbour seam; VE, Edwards seam; VI 9, Backpit seam.

Detection of Cellulose in Lignites.—Lignites free or relatively free from residual cellulose, as chemically determined (1), characteristically show a single exothermic peak. The samples of cellulose-free lignite studied thus far all have peak temperatures in the range of 420–430° C. The curves for fossil wood of Cyrilla and fossil wood of Gordonia in Figure 6 illustrate this group.

Lignites containing a relatively large amount of residual cellulose show dual exothermic peaks. The curves for stones [2] of fossil Nyssa (30 per cent

[2] Stone is used in the botanical sense and means the hard endocarp of a fruit.

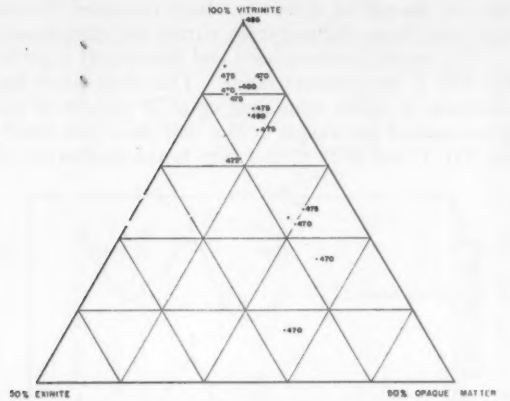

FIG. 13. Ternary diagram showing the relationship between petrographic composition and peak temperature. Samples are from II 1, Lloyd Cove seam, Sydney, Nova Scotia (high volatile A).

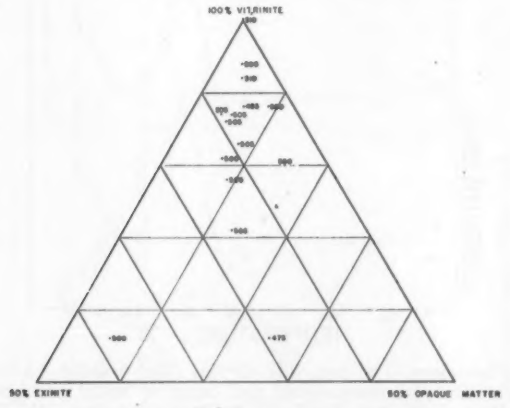

FIG. 14. Ternary diagram showing the relationship between petrographic composition and peak temperature. Samples are from X 2, Gardner seam, Sydney, Nova Scotia (high volatile A).

holocellulose) and Greek lignite in Figure 6 represent this group. This apparent duality is probably the result of an endothermic reaction superimposed on an exothermic reaction. The endothermic reaction results from the decomposition of the cellulose which reaches a maximum around 400° C. If cellulose had been absent in these two samples, each curve would probably have shown a single exothermic peak. Breger and Whitehead (2) have illustrated

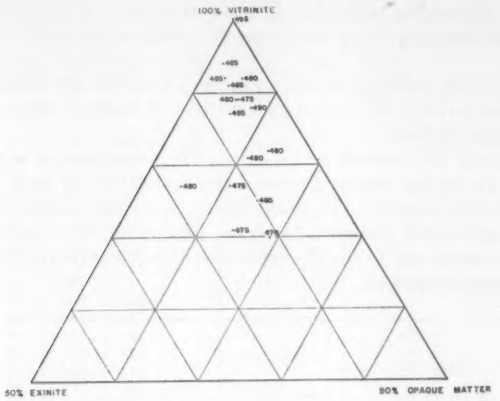

FIG. 15. Ternary diagram showing the relationship between petrographic composition and peak temperature. Samples are from XI 1, Mullins seam, Sydney, Nova Scotia (high volatile A).

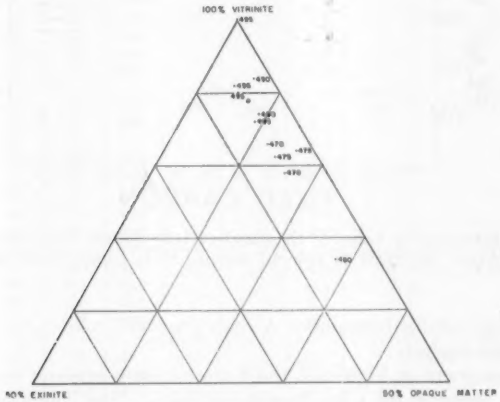

FIG. 16. Ternary diagram showing the relationship between petrographic composition and peak temperature. Samples are from XII 1, Tracy seam, Sydney, Nova Scotia (high volatile A).

these effects thermographically and have further shown that if the amount of cellulose is relatively small it will show only as a shoulder on the exothermic peak.

The endothermic peaks for a stone of fossil Nyssa and its holocellulose extract (Fig. 6) differ by 15° C. This difference is not great when one considers that in the former case where two reactions are superimposed slight

temperature differences might be expected to occur. A holocellulose extract from a stone of modern Nyssa can be seen to compare favorably with the above results.

Thermographic analysis provides a ready means for the detection of cellulose in lignites and it is felt that such a method of analysis might be placed on a semi-quantitative basis.

High Volatile Bituminous "A" Coals.—The experimental work on the bituminous A group has centered around the correlation of peak temperatures with fixed carbon content. Reproducibility of measurements has also been studied. Considerable attention has been directed to the relationship of macerals to the curves and to the discrepancies between petrographic, proximate and thermographic analysis.

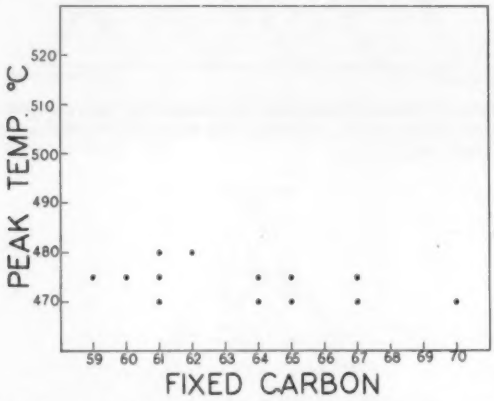

FIG. 17. Relationship between the fixed carbon content and peak temperature of the petrographic intervals in column sample II 1, Lloyd Cove seam, Sydney, Nova Scotia.

All the high-volatile bituminous A coals produced coke in the sample well during thermal analysis.

The thermograms in Figures 7 and 8 are for ten composite vitrain samples from various seams in the Cape Breton coalfields. The composites were obtained from column samples of each seam by picking the material from all vitrain bands of thickness over about 6 mm. Proximate analyses and differential thermal data for these samples are tabulated in Table 1. A scatter diagram relating the fixed carbon values and mean peak temperatures is shown in Figure 9 along with the line of regression. The correlation coefficient for this plot is 0.70 and with 95 percent probability the confidence limits are 0.13–0.92 There are at least three sources of error: proximate analyses, reproducibility of the peak temperatures and sampling. No attempt has been made to evaluate the error resulting from the proximate analyses, but it is felt that it might be of considerable magnitude.

TABLE 1

Seam name and Column sample No.	Wt. of sample, mgs	Beginning temp., °C	Peak temp., °C	Mean peak temp., °C	Std. deviation of peak temp., °C	Peak area, cm²	Std. deviation of area, cm²	Proximate analysis			
								Dry basis—percent			% F.C. mmf
								F.C.	Ash	Sulph.	
St. Rose—	30	360	480	479		6.6		54.92	5.98	4.36	59
Chimney	30	350	480			9.5					
Corner	30	355	475			7.5					
S.R. 1	30	355	480			7.1					
Backpit	25	370	505	507	±3	12.5	±1	59.84	3.16	2.31	62
VI 1 16	25	390	505			12.8					
	25	375	510			13.8					
	25	390	510			13.5					
	25	390	505			12.5					
	25	390	505			12.8					
	25	380	505			10.6					
	25	380	510			13.9					
	25	385	510			14.1					
	25	375	505			12.7					
Mabou	30	340	470	474		5.7		60.74	1.16	1.22	62
	30	365	475			3.4					
	30	355	475			8.5					
	30	360	475			5.2					
Lloyd Cove	30	365	485	484		5.4		60.65	1.65	2.46	62
II 1	30	375	485			5.7					
	30	375	480			7.5					
	30	370	485			5.9					
Mullins	25	370	490	494	±4	7.1	±1	61.71	2.95	2.36	64
XI 1	25	385	490			7.4					
	25	385	495			7.1					
	25	390	495			5.6					
	25	395	500			7.9					
	25	395	495			5.2					
	25	385	490			5.7					
	25	390	495			5.6					
Harbour	30	370	485	481		4.5		62.82	0.90	0.84	64
IV 3	30	365	480			6.6					
	30	360	480			8.1					
	30	360	480			6.4					
Tracy	30	380	495	496		12.1		60.88	2.30	3.77	64
XII 1	30	380	500			14.0					
	30	380	495			12.0					
	30	365	495			15.8					
Emery	30	380	505	509		12.5		63.83	1.57	1.29	65
IX 3	30	385	510			10.2					
	30	385	510			11.9					
	30	375	510			11.5					
Gardner	30	370	510	509		14.4		63.98	2.52	2.18	66
X 2	30	375	510			13.7					
	30	385	505			7.6					
	30	375	510			13.5					
Phalen	30	380	510	510		10.5		64.06	2.72	2.28	68
VII 2	30	385	510			11.1					
	30	375	510			13.0					

With regard to the reproducibility of replicate analyses, an examination of the data for samples VI 16 and XI 1 in Table 1 shows that the standard deviations for peak temperatures are ± 3° and ± 4° C respectively. Similar analyses using a smaller number of replicate determinations have all shown standard deviations not greater than ± 5° C. It is difficult to ascertain whether or not these standard deviations provide a good measure for the accu-

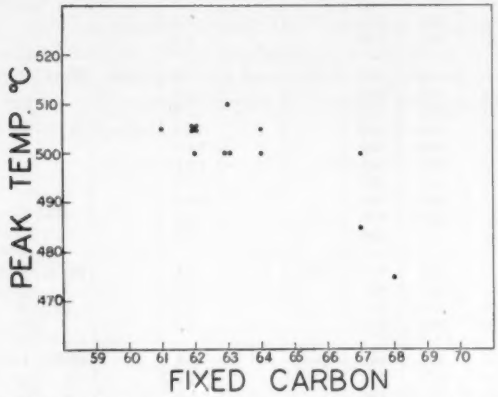

FIG. 18. Relationship between the fixed carbon content and peak temperature of the petrographic interval in column sample X 2, Gardner seam, Sydney, Nova Scotia.

racy of the method, since no standard by other workers is available for comparison. Table 1 also indicates that areas under the peaks can be reproduced to a surprising degree. Samples VI 16 and XI 1 both show a standard deviation in area of ±1 cm² or about 8 percent and 17 percent respectively. Considerably greater deviations in a number of the other samples may be related to the fact that the amount of sample used in other instances was slightly above

TABLE 2

Column sample No.	Sample block No.	Peak temp., °C	Area, cm²
IV 3	A1	475	6.8
	B8	480	8.1
	B28	480	7.3
	Composite	480	
IX 2	6	505	10.1
	7	505	13.5
	18	510	10.4
IV 1	A1	495	10.8
	B1	500	9.7
	C17	495	5.8
	C34	490	5.8

the optimum amount and that small heat losses occurred. The portion of the curves used for the determinations of area under the peaks is shaded in Figure 7. These areas are useful for judging reproducibility, but are incomplete for calorimetric measurements. In order to obtain a measurement of the heat evolved during a reaction the entire area under the peak would have to be measured. This is not practicable as the base line changes during carbonization, and any calorific determination would then be subject to a large error.

The error introduced by sampling has been investigated by analyzing different vitrain bands from the same column sample. A number of these curves are shown in Figure 10 and it can be seen that there is little change in the peak temperatures. More data on this point are tabulated in Table 2. Sample IV 1 shows the largest spread of 10° C. Further evidence will be presented

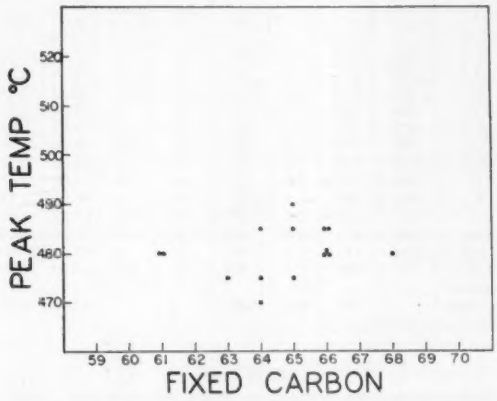

FIG. 19. Relationship between the fixed carbon content and peak temperature of the petrographic intervals in column sample XI 1, Mullins seam, Sydney, Nova Scotia.

below which shows that the peak temperatures remain relatively constant for different samples from a given column sample even in the case of the more heterogeneous banded ingredients (Tables 3–6; Figs. 17–19).

The thermograms in Figure 11 are all for sample VII 2. The amount of sample is varied to illustrate the effect on reproducibility. The outstanding differences brought about by increasing the sample size are: an increase in the area under the peak, and a decrease in the beginning temperature, that is, the beginning of the reaction is detectable at lower temperatures. The changes in peak temperature are only slight and fall within the limits of error. In this case, 30 mgs proved to be an optimum amount of sample. With larger amounts of sample the curves become distorted and reproducibility is poor.

In Figure 12 the thermograms represent composite vitrains from four seams cut by drillhole number 18 in the Sydney coalfield. It was felt that

such an experiment might show a linear relationship between peak temperatures and depth of burial. The temperatures do increase with depth but not in a linear manner. No effort has been made to interpret the pattern obtained.

In an attempt to determine the effect of the macerals on the thermographic peaks, a large number of samples of known petrographic composition were studied. These samples were prepared at the Coal Research Division of the Department of Mines, Nova Scotia, under the direction of Dr. P. A. Hacque-

TABLE 3

Seam name and Column sample No.	Petrographic interval	Beginning temp., °C	Peak temp., °C	Peak area, cm²	Petrographic composition, % by vol.			Proximate analysis			
								Dry basis—percent			% F.C. mmf
					Vitrinite	Exinite	Opaque matter	F.C.	Ash	Sulph.	
Lloyd Cove II 1	I	355	475	9.7	90	6	4	53.64	13.56	9.26	65
	II	355	475	8.9	92	6	2	57.99	5.17	4.80	60
	III	380	470	4.8	92	2	6	58.21	8.29	3.26	65
	IV	360	480	8.2	87	6	7	58.08	3.07	4.18	61
	V	375	475	5.7	81	10	9	55.09	10.76	7.14	64
	VII	365	470	4.0	72	8	20	50.10	21.30	11.10	70
	VIII	370	470	5.2	90	7	3	58.54	3.96	2.92	61
	IX	370	475	5.5	74	6	20	56.80	2.80	2.36	59
	X	365	480	7.2	91	5	4	58.21	3.79	3.83	62
	XI	365	470	7.5	57	17	26	58.87	5.48	4.05	64
	XII	380	475	4.6	85	6	9	57.77	3.53	3.71	61
	XIII	360	475	7.0	88	5	7	49.74	20.40	12.05	67
	XIV	365	470	5.6	67	8	25	47.70	22.90	12.40	67
	Vitrinite composite		485	6.2	100			60.65	1.65	2.46	62

TABLE 4

Seam name and Column sample No.	Petrographic interval	Beginning temp., °C	Peak temp., °C	Peak area, cm²	Petrographic composition, % by vol.			Proximate analysis			
								Dry basis—percent			% F.C. mmf
					Vitrinite	Exinite	Opaque matter	F.C.	Ash	Sulph.	
Gardner X 2	III	360	485	6.5	88	6	6	47.95	23.00	9.35	67
	V	375	505	13.6	78	13	9	55.24	11.56	5.42	64
	VII	360	505	13.4	86	9	5	56.99	6.42	2.96	62
	VIII	350	505	16.3	87	9	4	58.76	3.86	2.45	61
	IX	365	500	14.8	56	38	7	57.37	6.23	3.68	62
	X	355	505	12.5	83	9	8	55.34	8.06	5.68	62
	XI	365	505	11.3	71	16	13	52.69	11.86	6.59	62
	XII	365	500	10.7	81	12	7	54.64	10.50	6.24	67
	XIV	345	500	12.8	94	3	3	58.28	5.22	3.82	63
	XV	360	500	13.7	80	5	15	56.37	8.80	3.09	63
	XVI	370	475	7.5	56	19	25	42.07	33.93	3.14	68
	XIX	350	510		92	4	4	54.50	9.78	7.10	63
	XX	360	500	12.9	88	3	9	54.76	11.06	6.10	64
	XXI	370	505	13.1	87	8	5	55.20	8.32	5.18	62
	Vitrinite composite		510	13.9	100			63.98	2.52	2.18	66

TABLE 5

Seam name and Column sample No.	Petrographic interval	Beginning temp., °C	Peak temp., °C	Peak area, cm²	Petrographic composition, % by vol.			Proximate analysis			
								Dry basis—percent			% F.C. mmf
					Vitrinite	Exinite	Opaque matter	F.C.	Ash	Sulph.	
Mullins XI 1	V	350	480	7.4	81	8	11	51.18	19.02	11.00	68
	VII	375	475	6.3	89	5	6	61.83	3.02	3.24	65
	VIII	355	485	8.3	87	7	6	60.42	3.78	3.29	64
	IX	375	480	6.2	77	18	5	57.51	4.34	2.32	61
	X	365	485	8.3	92	5	3	59.28	7.62	5.84	66
	XI	375	475	4.9	71	15	14	56.79	7.73	5.03	63
	XII	360	485	8.7	94	4	2	59.50	6.02	3.57	65
	XIV	355	485	9.8	91	5	4	59.39	7.06	5.06	66
	XV	380	480	5.0	89	5	6	55.70	12.30	6.54	66
	XVI	360	475	6.3	77	12	11	51.92	14.78	7.66	64
	XVIII	365	480	4.6	75	10	15	55.11	12.85	6.28	66
	XIX	375	480	5.2	93	3	4	56.98	4.82	3.45	61
	XX	365	490	7.3	88	4	8	59.38	6.02	4.44	65
	XXI	370	480	6.5	82	5	13	54.04	12.76	8.42	66
	XXII	365	470	5.8	70	11	19	54.47	12.05	5.54	64
	Vitrinite composite		495	6.5	100			61.71	2.95	2.36	64

TABLE 6

Seam name and Column sample No.	Petrographic interval	Beginning temp., °C	Peak temp., °C	Peak area, cm²	Petrographic composition, % by vol.		
					Vitrinite	Exinite	Opaque matter
Tracy XII 1	I	355	470	6.8	83	5	12
	II	360	495	12.4	90	5	5
	IV	355	495	15.4	91	5	4
	V	355	490	11.2	87	4	9
	VI	355	490	10.5	81	5	14
	VII	355	490	12.5	92	2	6
	VIII	360	480	10.3	67	5	28
	IX	360	475	9.3	82	2	16
	X	380	475	5.2	44	8	48
	XI	360	495	14.0	86	5	9
	XII	360	470	4.1	79	5	16
	Vitrinite composite		495	13.5	100		

bard. Petrographic divisions were established in four column samples of different seams. These petrographic divisions are based on the relative amounts of the various banded ingredients over a vertical interval of the seam (4). Representative samples were taken from each petrographic interval and maceral contents were determined microscopically using polished sections of ground coal mounted in lucite, and on an integrating stage (5, p. 512). The petrographic, thermographic and chemical data on these samples is shown in

Tables 3–6. The relationship between petrographic composition and peak temperature is illustrated graphically on ternary diagrams (Figs. 13–16). The 100 percent vitrinite samples are composites of various pure vitrain bands in each column sample and serve as an internal standard for the vitrinite in each of the four column samples studied. The composition of each petrographic division is indicated by a point within the composition triangle and the corresponding number signifies the peak temperature. From a study of these diagrams it becomes apparent that neither the exinite nor the opaque matter exerts any evident control on the peak temperatures. The results are essentially random.

The relationship between the fixed carbon content of the petrographic intervals and peak temperature is shown in Figures 17–19. In Figure 17, thirteen samples all have peak temperatures between 470° C and 480° C while the fixed carbon varies from 59 to 70 percent. The same general tendencies are also evident in Figures 18 and 19, although the fixed carbon values do show a better grouping. In both cases, with the exception of two points in each graph, all the peak temperatures fall within 10° C limits. The spread for the specimens from column sample XII 1 is considerably greater. Unfortunately, proximate analyses are not available for these samples.

SUGGESTIONS FOR FUTURE WORK

The thermographic peaks present a graphic representation of the net effects of the physical and chemical changes that take place in a sample during carbonization. With the technique and apparatus used in this research, this net effect proves to be exothermic. In order to determine the individual effects of some of the processes that go on during carbonization, an attempt should be made to correlate rate of gas evolution and plasticity measurements (softening and solidification temperatures and swelling numbers) with the thermographic characteristics such as peak temperature, beginning temperature, inflectional zone between these two temperatures, and peak area. A more empirical but possibly more practical approach would be to investigate the possibility of correlating the above mentioned parameters of the peaks with the properties of coke obtained on a laboratory scale. Some vitrains and bright coals give characteristically large peak areas while others, even from the same column sample, may be small. For example, sample IV 1 A1 and B1 of Table 2 have respective areas of 10.8 and 9.7 cm^2. while C17 and C34 from the same column are only 5.8 cm^2. Differences such as these may indicate differences in coking properties.

It is now known that through the use of different thermographic techniques very different effects can be obtained. Glass (3) has obtained sharp endothermic peaks using conventional differential thermal analysis equipment. It is thought that either method may possess its own peculiar merit to aid in predicting the physical properties of a coke. Further comparison of the two methods is to be desired.

CONCLUSIONS

The experimental data collected on ten vitrain samples from coal of the high-volatile bituminous A group indicate that there is an apparent correlation between peak temperature and fixed carbon content. The authors are fully aware of the fact that investigation of many more samples than the ten used to determine the correlation factor is desirable before this correlation can be established with adequate precision by statistical methods. Any conclusions now drawn must, therefore, be considered tentative.

It has further been shown (Figs. 17–19) that there is no correlation between the peak temperature and fixed carbon in samples from each column for three coals varying in fixed carbon content from about 60 to 70 percent and having a complex petrographic composition. Although the range of variation in the peak temperature for most of the samples in each of these three columns is less than that for the fixed carbon, a few peak temperatures appear to be erratic. The peak temperature seems to offer a better index of rank than the fixed carbon in samples having a complex petrographic composition.

It appears, therefore, that the fixed carbon value of a vitrain provides a better index of rank than that of an average sample of coal composed of various banded ingredients. This confirms the suggestion of Seyler that the rank of coal must be judged by the properties of the vitrinite and not by those of an average sample (6, 7).

Further conclusions are that thermographic analysis is a useful method for the detection of cellulose in lignites and that the chemical fraction of the coal extractable in pyridine gives rise to the peaks.

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April 15, 1954

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THE FALCONBRIDGE ORE DEPOSIT, CANADA

D. R. LOCHHEAD

THE Falconbridge Ore Deposit [1] is located on the southeast corner of the Sudbury Basin in Falconbridge Township and was first discovered by Thomas Edison about 1900, by geophysical methods. He attempted to reach the ore body by a shaft but failed due to quicksand in the covering layer of overburden. It remained for the Longyear Drilling Company of Minneapolis to prove by drilling in 1916 that Edison had actually located an ore body. Ventures Limited bought the property from the Longyear Company and brought the mine into production in 1930, under the direction of its newly formed "Falconbridge Nickel Mines Limited."

The mine is approximately one mile in length and the deepest workings to date are at 4,025 feet. The deepest known ore to date from the underground drilling is some 5,600 feet below surface.

This ore deposit is similar mineralogically to the other ore deposits of the Sudbury Basin in that it consists essentially of an assemblage of pyrrhotite, pentlandite, and chalcopyrite, commonly enclosing fragments of wall rock. It is somewhat more individualistic in that it is a continuous and well defined sheet of sulphides extending roughly east-west and standing almost vertically, with a small average dip to the south, away from the Basin.

Structurally, the deposit occupies a zone between the norite of the Basin and the adjoining greenstone. Its most pronounced features are, first, its continuance to a depth of at least 5,600 feet without straying from the norite contact, and secondly, the occurrence along one, or both walls, of strong gouge-filled faults exhibiting post-ore movement. In almost all cases the sulphides are enclosed between these gouge walls. Generally, however, where only one gouge fault is present, the other wall is a knife-like frozen contact. In places the sulphides penetrate the wall rocks as stringers and isolated ore shoots, a feature that is becoming more prevalent with depth.

The ore zone varies in thickness from a few inches to over one hundred feet and averages approximately fifteen feet. These variations are illustrated by the ore thickness contours shown in Figure 1. Swells, or thickenings, in the ore zone in most cases can be attributed to local or secondary structures, principally tangential shears or fractures intersecting the main shear.

Figure 2 is a grouping of (100-scale) geological plans of the five levels 2450 to 3150 inclusive. In a composite plan these levels would, of course, be piled one on the other but for clarity are here shown pulled apart along

[1] Previously described by Dr. S. C. Davidson in C. I. M. Trans., Vol. XLIX, 1946. In view of the newer deeper workings of the mine, the present paper is intended to extend the picture presented by Dr. Davidson at that time.

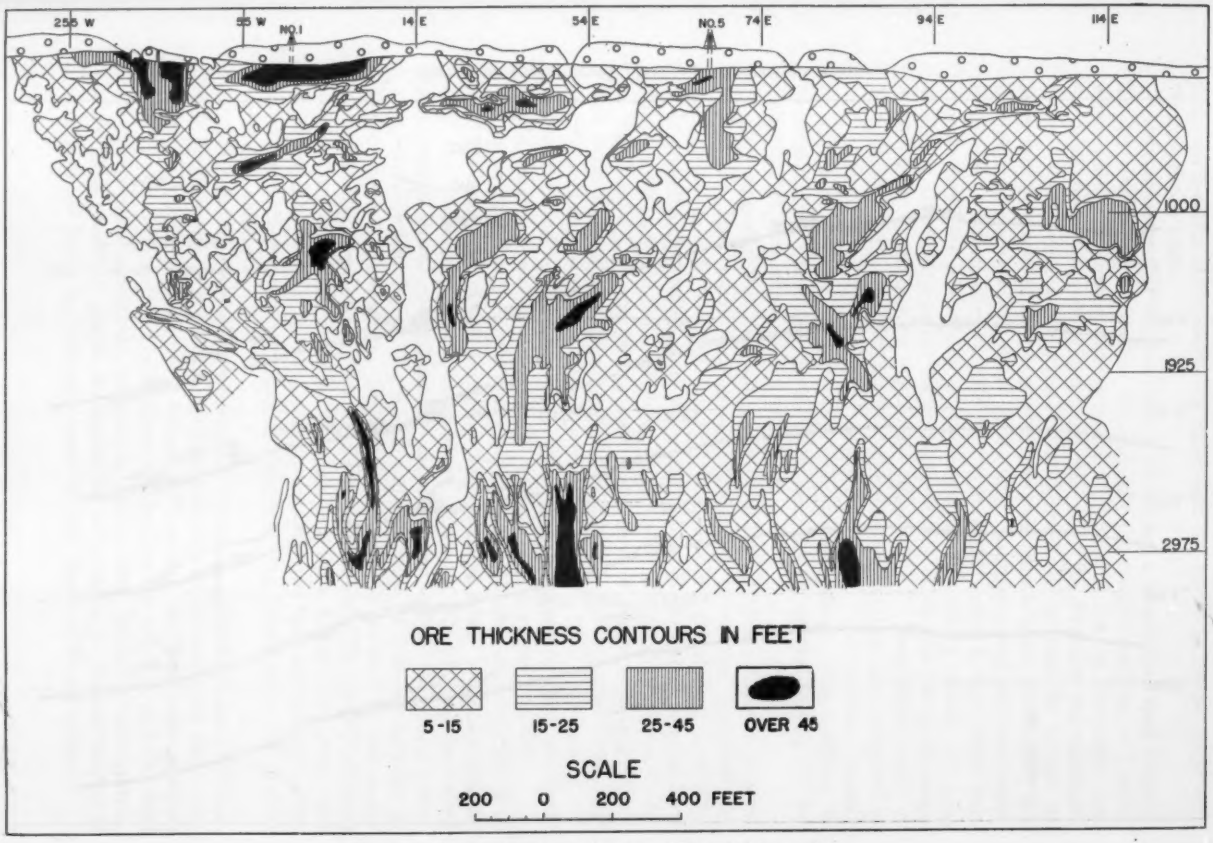

FIG. 1. Longitudinal projection—Falconbridge mine.

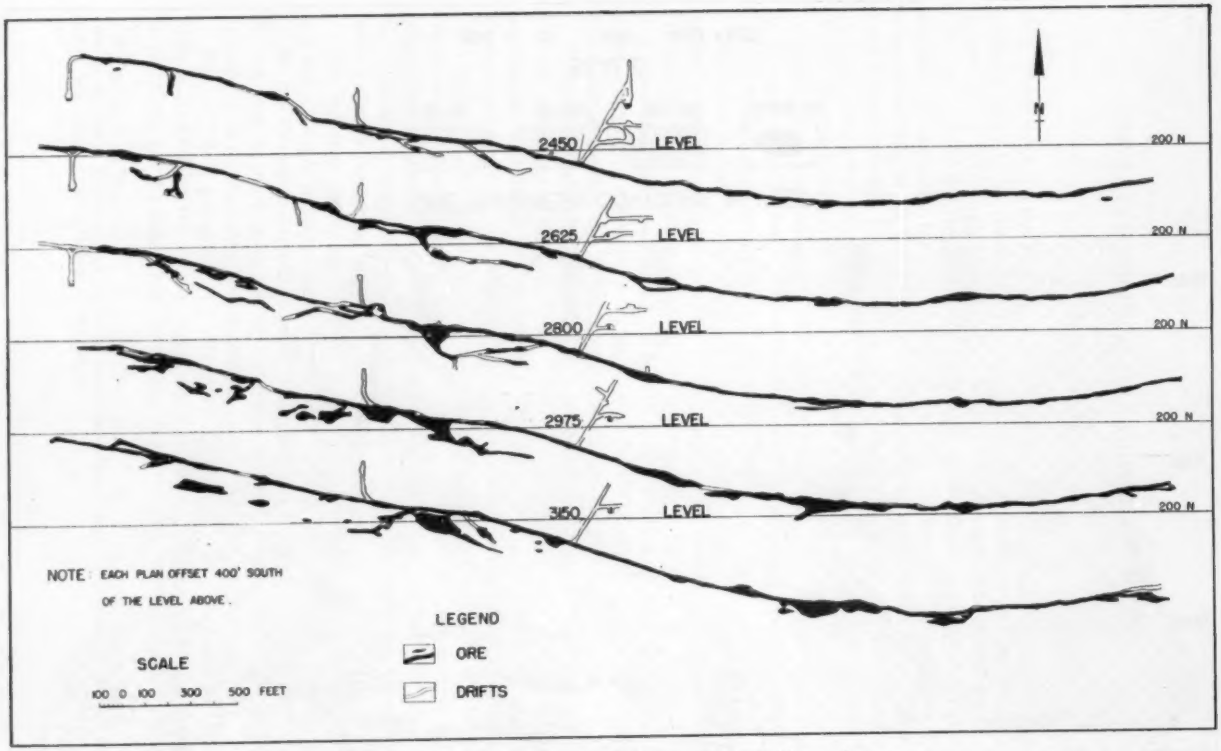

FIG. 2. Series of lower level plans—Falconbridge mine.

their north-south coordinates. In each case the norite is to the north and the greenstone south.

It is apparent that the ore zone is in essence a mineralized fault contact. To the west, along the strike, the fault and the contact separate at a point where the norite contact swings to the southwest in Garson Township, and the fault trends into the Basin. At this point of diversion the sulphides cease. To the east, in the mine, the fault breaks away from the contact by steps into the greenstone. As a result, as each branch leaves the contact, the ore becomes more rocky until all of the fault has disappeared and the contact is barren. Approximately 2,000 feet east of this point a new shear zone appears from the norite and joins the contact to make a second ore zone similar in all respects to the Falconbridge mine. This new ore zone, under development at present, is called the "East Mine." Immediately west of Falconbridge mine some 2,000 feet of norite contact has been explored at the surface, on the 1750 level, and on the 2600 level. This section of contact is unsheared and has proven essentially unmineralized. The evidence is conclusive that where post-basin faults are lacking on the contact, in the Falconbridge area, there are no ore zones.

It is suggested that the fault zones, constituting the ore zones at Falconbridge and East mines, are actually pre-Basin faults that governed the position of the outer edge of the norite intrusive in Falconbridge Township. This undoubtedly explains why this corner of the Basin has a steep outward dip, in contrast to the flat inward dip, so typical of almost all of the remainder of the Basin. Carrying this thought a step further, there is some evidence that these Falconbridge shear zones connect with the Cameron Creek and Fairbank fault systems striking westerly through the Basin and passing out of the west end. It is conceivable that this system results from pre-Basin breaks that may have been the source opening for the entire irruptive.

Apparently the pre-Basin faults were reactivated after consolidation of at least the outer edge of the irruptive. Consequently, where the faults coincide with the norite-greenstone contact there resulted a schisted and brecciated zone, which served as the locus for ore deposition. Both norite and greenstone were broken during this period and fragments of both are included in the ore zone. Evidently the reactivation of the fault occurred in two stages with the early stage being primarily a schisting, followed by quartz-carbonate veining and silicification. This was followed by a further disruption that resulted in brecciation, as evidenced in the ore zone by numerous inclusions exhibiting well-preserved small drag folds, schisting, silicification, and quartz-carbonate veining.

The rocks that enclose the ore deposit are norite, greenstone, and jasperoid. The fresh norite is a massive medium-grained, ophitic textured rock, consisting essentially of 50 percent feldspar, 40 percent ferromagnesian minerals and 10 percent quartz. The feldspar is oligoclase to andesine, and the chief ferromagnesian mineral is hornblende and a little biotite. Consequently, the rock is actually a quartz diorite but the term norite is retained because of its use in the Basin to denote the outer or basic phase of the irruptive.

The greenstone is a fine to medium-grained hornblendite that is thought to have been derived from lava flows of the composition of dacite, by regional metamorphism. It is composed essentially of hornblende and clinozoisite and in places with biotite excluding the clinozoisite. Chlorite and quartz are replacement minerals, with the chlorite the earlier. It has attacked the hornblende and biotite primarily, and in places the clinozoisite. The quartz replaces all minerals, including the chlorite. A small outcrop of greenstone on the surface at the East mine exhibits pillows, but these have not been recognized underground.

The norite and greenstone were both subjected to early silicification, which resulted in a fine-grained rock megascopically resembling quartzite or jasper. This altered rock has been locally named jasperoid. Generally the greenstone derivative is gray in color, whereas the norite has been altered to blue jasperoid. The silicification is pre-ore and will be referred to again.

As mentioned previously, the schisting and brecciation affected both the norite and greenstone, whereas the jasperoid is only affected by the brecciation. Both rock types occur as fragments in the ore, exhibiting various degrees of schistosity and silicification. It is significant that in the deeper levels of the mine, the fragments tend to be largely rags of schist, whereas in the upper parts of the mine, rounded and unsheared breccia fragments were most prominent and fresh norite inclusions were relatively common. Apparently brecciation was more effective in providing the permeable zone near surface, whereas the added load in the deeper workings was such that shearing prevailed.

The norite and greenstone are structureless, and in addition they contain essentially no cross-cutting dikes. As a result, it has not been possible to measure displacement along either the strike fault or the few cross faults in the mine. It has previously been inferred that the north or norite side of the ore zone moved up and to the west. This, however, is now questioned in the light of the fact that the fault zone is known to be south dipping to the 5600 horizon. Most faults in the district are thrust faults, which would make the Falconbridge movement south side up.

Earlier in this paper I referred to the dip of the ore zone (along with the norite contact) as being steeply south. Actually it dips steeply north at the surface (towards the Basin) but at a short depth it rolls over to a south dip, which is now known to persist to the 5,600-foot horizon. This south dip varies between 65 and 80 degrees. The depth to the point of reversal changes along the strike but for simplicity in description it is here averaged at approximately the 1,200-foot horizon. This reversal in dip has provided some interesting clues on the origin and timing of the sulphides, the silicification, and the alteration in the norite.

In general, above the point of dip reversal, most of the swells, parallel ore shoots, sulphide spots, stringers, and silicification have been found on the north, or norite, side of the main zone. Below this point the reverse is true and such features occur on the south side of the main break. In both cases the hanging wall is favored, and the footwall is almost completely ignored by the pre-ore silicification and the ore carriers. Since the swells and

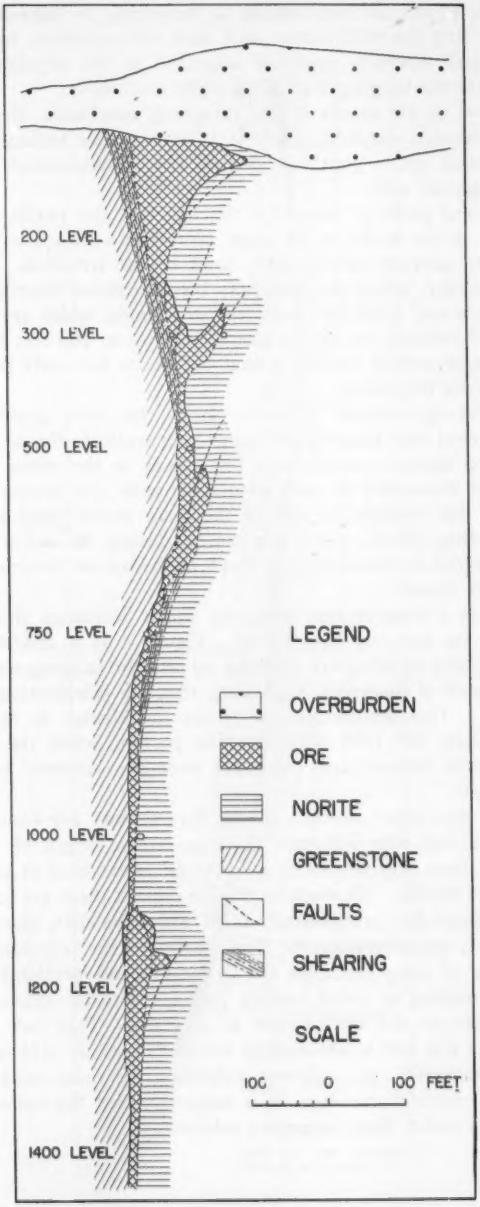

FIG. 3. Geological cross-section—Falconbridge mine (looking west).

separated ore shoots are attributable to branching or subsidiary shears, it appears that, first the silicification, and later the sulphides, travelled up the main zone, and wherever openings appeared in the adjoining walls they worked up into the hanging wall along these fractures.

Irrespective of the merits of the foregoing conclusion, the fact remains that a very valuable empirical guide is at hand in ore finding. In exploration, the footwall can be generally ignored and all exploration efforts turned to the hanging wall side.

An additional point of interest is the fact that the swells, stringers, and dissemination in the norite of the upper workings were apparently restricted to a relatively narrow chilled outer band of the irruptive. In the lower workings, however, where the subsidiary breaks entered the rigid greenstone, the silicification and sulphides were free to wander, which resulted in many branching and isolated ore shoots that extend up to 100 feet from the main zone. The inference, of course, is that the norite had only partially cooled at the time of ore deposition.

Finally, the dip reversal serves to clarify one other controversial issue. The only material ever found in the mine comparable to the so-called "quartz diorite" of the district, occurs at a few places in the norite of the upper workings, and associated in each case with wide ore sections. It is now believed that this material is part of the main norite mass altered by the upward travelling fluids, either pre-ore or during the ore-making period. This altered norite is consequently a result of the intense mineralizing activity rather than the cause.

Figure 3 is a cross-section from the upper workings showing the ore swelling into the hanging wall norite. Figure 4 is a smaller-scale cross-section of the mine showing ore reaching up into the hanging wall greenstone. Note the aureole of jasperoid, suggesting that the silicification travelled beyond the ore. This section also illustrates the change in dip from north to south at about the 1200 horizon. The portion below the 4025 level is interpolated from inclined drill holes and must be considered subject to correction in detail.

There are two other features of the deposit that are common to other Basin deposits, and may influence thinking on the origin of the sulphides. In both cases their significance is not wholly understood at present and is mentioned only briefly. Throughout the ore deposit there are numerous post-ore cross-fractures that are generally filled with sphalerite, galena, marcasite, and carbonates, apparently by the final phases of the ore-making solutions. On both sides of these fractures the pyrrhotite and pentlandite have been altered to a complex of nickel-bearing pyrite, marcasite, bravoite and other minerals foreign to the ore deposit as a whole. This halo of alteration extends from a few feet to as much as ten feet on either side of the fracture and grades uniformly to unaltered sulphides. Because such a condition persists to the deepest workings, it is suggested that the responsible agents were hypogene rather than supergene solutions.

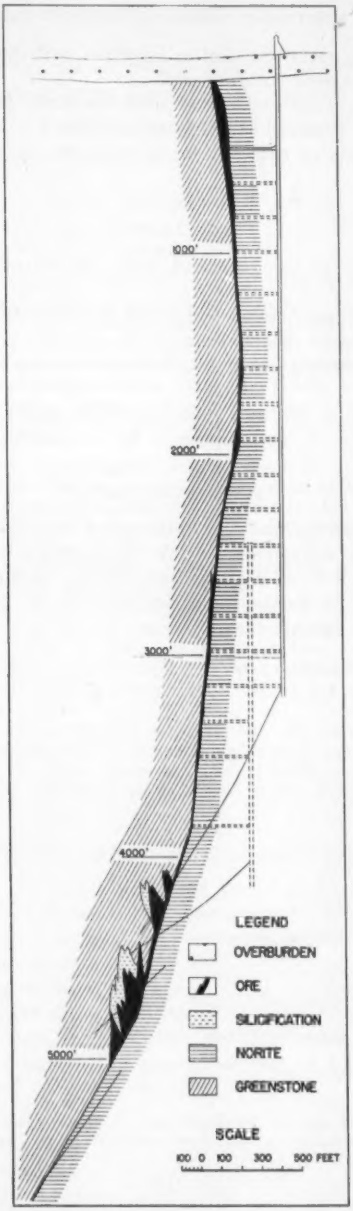

FIG. 4. Geological cross-section through No. 5 shaft—Falconbridge mine (looking west).

Finally, there is appreciable evidence of zoning in the deposit as shown by:

1. An increasing ratio of nickel to sulphides with depth and with distance into the greenstone hanging wall.
2. The presence of early arsenides in the ore zone, which were unquestionably partially replaced by the later sulphides.
3. Increased ratio of chalcopyrite to sulphides in the hanging wall ore shoots.

CONCLUSIONS

1. The ore deposit was emplaced after the arrival and partial cooling of the norite.

2. The ores reached their present position by travelling upwards from the source in an extremely mobile state.

3. Post-Basin faulting along the norite-greenstone contact provided the ore channels.

4. Post-Basin faults probably reflect pre-Basin faults that served to delimit part of the outer edge of the irruptive in the Falconbridge area.

ACKNOWLEDGMENTS

I wish to acknowledge that I have borrowed from the results of Dr. E. L. Evans' microscopic work and W. W. Westaway's structural studies at Falconbridge. In addition, I have been assisted in the preparation of this paper by others at Falconbridge, principally G. P. Mitchell, Chief Mine Geologist, and A. D. Mutch, Geologist.

FALCONBRIDGE, ONTARIO,
June 8, 1954

THE GEOCHEMISTRY AND ORIGIN OF THE GOLD BEARING QUARTZ VEINS AND LENSES OF THE YELLOWKNIFE GREENSTONE BELT [1]

R. W. BOYLE

ABSTRACT

The economic gold quartz veins and lenses at Yellowknife occur within shear zones in steeply dipping greenstones (amphibolites) of Precambrian age. The shear zones consist of chlorite schist that has been highly altered in the vicinity of the quartz veins and lenses. The zones of alteration enveloping the quartz bodies include an adjacent carbonate-sericite zone and an outer chlorite-carbonate zone that grades into the chlorite schist of the shear zone. Throughout the shear zones extensive chlorite-carbonate areas are present and these show no close relationship to the quartz bodies.

Chemical analyses of samples taken across the strike and down the dip of the shear zones show that there is a marked loss of SiO_2 in the chlorite schist of the shear zones, when compared with the amphibolite of the wall rocks. This loss increases in the chlorite-carbonate zones and reaches a maximum in the carbonate sericite zones. In one shear zone where the quartz lenses occur above extensive carbonate-chlorite schist portions, a marked decrease in SiO_2 with depth is evident.

Graphs of the chemical analyses across the width of the alteration zones indicate that the loss of SiO_2 is compensated for by the addition of CO_2 and H_2O. The shape of the SiO_2 concentration line, exhibiting a low adjacent to quartz bodies, and increasing in value outward toward the wall rock, indicates that SiO_2 has migrated toward the present site of the quartz bodies.

The chemical evidence strongly suggests that CO_2 and H_2O from mineralizing solutions displaced SiO_2 from the alteration zones and chlorite-carbonate areas of the shear zones and that this SiO_2 migrated toward dilation zones within the shear zones where it was deposited as quartz veins and lenses.

INTRODUCTION AND ACKNOWLEDGMENTS

THIS paper describes the quartz veins and lenses of the Yellowknife greenstone belt and attempts to show from geochemical data that the quartz in these lenses has been derived from alteration processes within the shear zones in which the quartz bodies occur.

The Yellowknife greenstone belt occurs along the west shore of Yellowknife Bay on the northern shore of Great Slave Lake, Northwest Territories, Canada. Two gold mines, the Con mine and Giant mine, are at present the only gold producing mines in the greenstone belt; a former producer, the Negus mine, suspended operations in 1952.

[1] Presented before the Society of Economic Geologists, Toronto Meeting, 1953, and published by permission of the Deputy Minister, Department of Mines and Technical Surveys, Ottawa, Canada.

The field work upon which this paper is based was carried out in the summers of 1950, 1951, and 1952, during a detailed investigation of the gold deposits of the Yellowknife area for the Geological Survey of Canada.

I wish especially to thank the mine operators and geologists of the Giant, Con, and Negus mines for their many courtesies and for permission to use their underground plans and sections and some of their analytical data. Dr. J. F. Henderson has read and criticized the paper, but may not necessarily agree with all the conclusions; to him the writer is grateful.

GEOLOGICAL OCCURRENCE AND DESCRIPTION OF THE ECONOMIC QUARTZ VEINS AND LENSES

The economic gold-quartz veins and lenses of the Yellowknife greenstone belt occur within shear zones in steeply dipping metamorphosed andesite, basalt, and minor dacite flows of Precambrian age. Three principal shear zone systems have been outlined which are called the Con shear system, the Giant-Campbell system, and the Negus-Rycon system. These systems are shown on Figure 1.

The Con and Giant-Campbell are sub-parallel systems. They consist of several wide interlacing shear or schist zones separated by horses and masses of massive or only slightly altered country rock. The Negus-Rycon system is a cross-over system between the two larger systems. It consists of a number of narrow shear zones that branch and join throughout their extent. A detailed description of the shear zone systems can be found in a paper by the author (1).[2]

The rock composing the shear zones where mineralization is weak or absent is a chlorite schist that shows varying degrees of foliation. Where quartz lenses and veins are present in the shear zones they are enveloped by a characteristic alteration halo as illustrated in Figure 2. This halo includes an adjacent carbonate-sericite zone and an outer chlorite-carbonate zone, which in turn grades into the chlorite schist of the shear zone. Extensive carbonate-chlorite and carbonate-sericite alteration zones are present throughout the three shear zone systems. In some shear zones these alteration zones occupy the central portion of the shear zone and extend along the strike and dip for considerable distances; in others they are localized where severe mashing and contortion of the schist of the shear zone has taken place. These altered zones are not closely associated with quartz bodies in most cases, but as will be demonstrated in this paper they have an important bearing upon the origin of the silica in the quartz lenses. Figures 3 and 4 show the spatial relationships of quartz bodies to alteration zones in two shear zones studied.

In the Con and Giant-Campbell shear systems the quartz occurs as irregular lenses and vein-like bodies. The boundaries of the lenses are irregular, and the lenses themselves contain abundant seams, patches, and irregular areas of carbonate-sericite schist. Two ages of quartz are present, an early white to gray variety that makes up most of the quartz occurring in the lenses, and a later white to flesh-colored variety that crosscuts the lenses. This paper is

[2] Numbers in parentheses refer to References at end of paper.

concerned only with the origin of the early variety, and no mention of the origin of the second age of quartz will be made. The Negus-Rycon system is characterized by a series of narrow well-defined quartz lenses and veins. As in the Con and Giant-Campbell systems the quartz lenses and veins in this system contain quartz of two distinct ages. The early variety forms the bulk

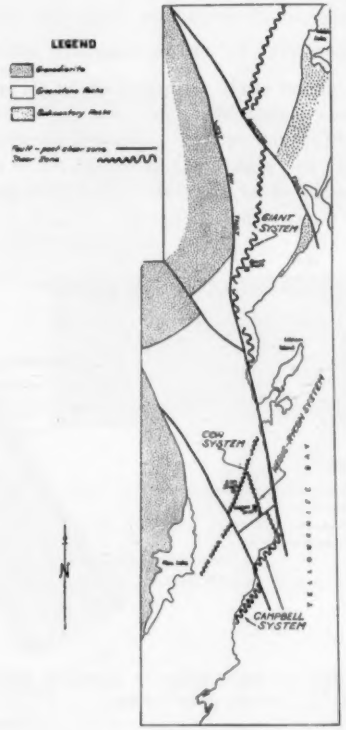

FIG. 1. Geological map of the Yellowknife greenstone belt.

of the lenses and veins, is black to dark gray in color, and is cut by small stringers of secondary white to gray quartz. In the three systems, all quartz lenses and veins and their adjacent alteration haloes contain pyrite and arsenopyrite in varying amounts. Sulphosalts, stibnite, sphalerite, and gold occur in the veins and lenses of ore grade.

In all shear zones the quartz bodies occur at the junctions of shear zones or where deflections in the strike and dip of the shear zones occur. These sites were probably dilatant zones, i.e., low-pressure zones, toward which mineralizing solutions have carried and deposited silica and other minerals. For a more detailed description of the structural localization of the quartz bodies the interested reader is referred to a paper by the author (2) published elsewhere.

GEOCHEMISTRY OF THE ALTERATION ZONES

An extensive thin section study accompanied by a chemical study of the country rocks, shear zones, alteration zones, and quartz lenses has been carried out on the three shear zone systems. Several alteration phases occur in the shear zones, but only four phases will be considered in detail in this paper. These are the chlorite-schist phase, the carbonate-chlorite phase, the carbonate-sericite phase, and the quartz phase (Fig. 2).

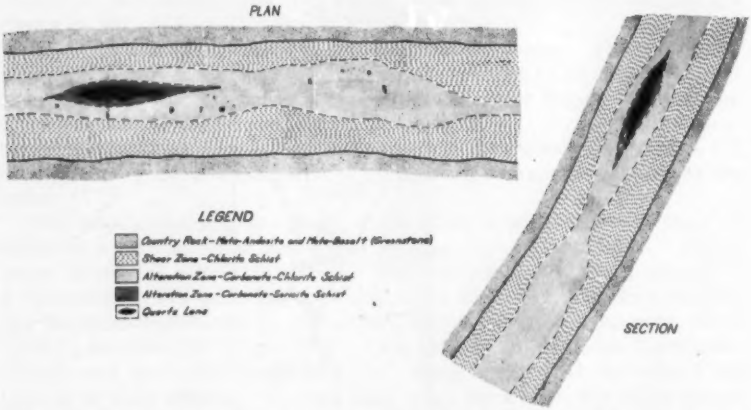

FIG. 2. Sketch illustrating the relationship of alteration zones to quartz lenses in all shear zones.

The country rock is an amphibolite composed mainly of a fibrous amphibole which is probably tremolite, and oligoclase, epidote, magnetite, leucoxene, sphene, quartz, chlorite, pyrite, and carbonate in that order of abundance. The amphibole shows a tendency to be oriented in some thin sections, but in general the rock is massive and exhibits little schistosity.

Within the shear zones the chlorite schist phase occupies the outer zone in mineralized areas and is the predominant rock where mineralization is weak or absent. Thin sections of this rock contain green chlorite, albite, ankerite, leucoxene, and pyrite. In both thin sections and hand specimens the rock possesses a high degree of foliation.

As a quartz vein or lens is approached, the chlorite-schist phase passes imperceptibly into the carbonate-chlorite phase. Thin sections of this rock contain equal amounts of ankerite and chlorite, albite, and small amounts of quartz, sericite, leucoxene, and pyrite. The rock exhibits a high degree of foliation in both thin sections and hand specimens. The carbonate-chlorite phase is not restricted to the alteration halo enveloping quartz lenses, but as mentioned previously this phase may occur in extensive zones in other parts

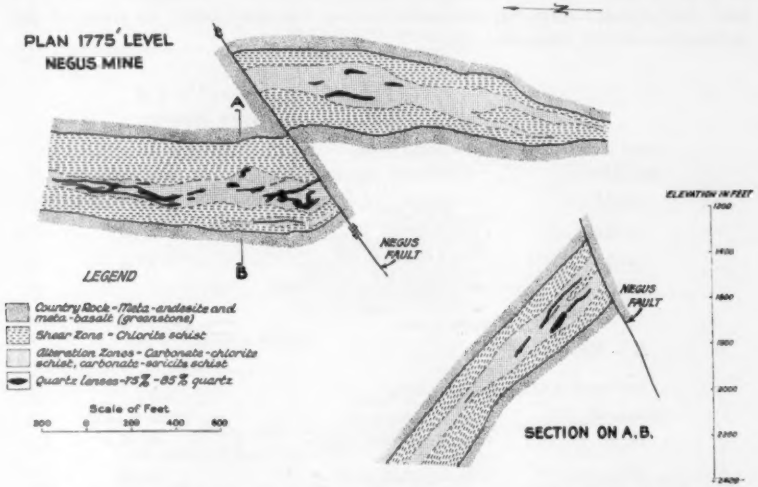

FIG. 3. Typical geological plan and section of the Campbell System showing relationship of alteration zones to quartz lenses, Negus Gold Mines, Yellowknife, N. W. T.

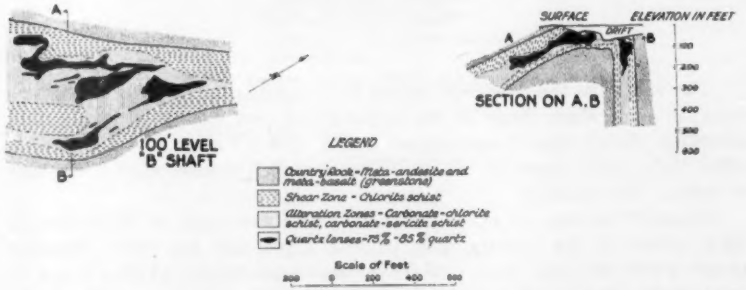

FIG. 4. Typical geological plan and section of the Giant system showing relationship of alteration zones to quartz lenses, Giant Yellowknife Gold Mines, Ltd., Yellowknife, N. W. T.

of the shear zones. Next to the chlorite schist phase the carbonate-chlorite phase is the most common type of alteration in the shear zones.

Immediately adjacent to nearly all quartz lenses the carbonate-chlorite phase grades into the carbonate-sericite phase. In this phase sericite is the characteristic mineral, but ankerite is equally abundant. Other mineral constituents are chlorite, pyrite, arsenopyrite, leucoxene, and quartz. The carbonate-sericite phase like the chlorite-schist phase possesses a high degree of foliation both in thin sections and hand specimens. This phase shows its best development adjacent to quartz bodies but may occur in some of the carbonate-chlorite alteration zones.

TABLE 1

TOTAL SiO_2 ANALYSES FROM THE NEGUS–RYCON SYSTEM

3rd level, 300 feet, Negus Mine

Sample No.	Description	Total % SiO_2
YC-22	Greenstone, chip sample across 50 feet	51.71
YC-23	Chlorite schist, channel sample across 1 foot	44.53
YC-24	Carbonate-chlorite schist and carbonate-sericite schist, composite channel sample across 1 foot	41.74

J. A. Maxwell, Analyst

11th level, 1,425 feet, Negus Mine

Sample No.	Description	Total % SiO_2
YC-1	Greenstone, chip sample across 250 feet	48.46
YC-2	Chlorite schist, channel sample across total width of chlorite schist zone 1 foot 6 inches	44.27
YC-3	Carbonate-chlorite and Carbonate-sericite zone. Composite channel sample across total width of 6 inches	40.97

R. J. C. Fabry, Analyst

The widths of the alteration phases vary extensively throughout the systems; in some shear zones of the Negus-Rycon and Con Systems all three alteration phases may be compressed into a zone a few inches in width; in other shear zones, especially in the Giant-Campbell system, each phase may be tens of feet in width.

Chemical analyses (Tables 1, 2, 3, 6) have been made to determine the SiO_2 content of the country rock, chlorite schist, and the other alteration phases within the shear zones. Complete chemical analyses (Tables 4 and 5) were made of samples from zones where the alteration phases are clearly defined. All samples were chip or channel samples taken along crosscuts across the shear zones at different levels in the various mines.

TABLE 2

TOTAL SiO_2 ANALYSES FROM THE CAMPBELL SYSTEM

11th level, 1,425 feet, Negus Mine

Sample No.	Description	Total % SiO_2
YC-4	Greenstone, chip sample across 250 feet	47.97
YC-5	Chlorite schist, some chlorite-carbonate schist, chip sample across 70 feet	41.93
YC-6	Carbonate-chlorite and carbonate-sericite schist. Small quartz lenses and stringers. Chip sample across 2 feet	43.55

R. J. C. Fabry, Analyst

13th level, 1,775 feet, Negus Mine

Sample No.	Description	Total % SiO_2
YC-7	Greenstone, chip sample across 250 feet	47.72
YC-8	Chlorite schist, some chlorite-carbonate schist, chip sample across 50 feet	43.91
YC-9	Carbonate-chlorite and carbonate-sericite schist. Composite chip sample across 3 feet	42.93

R. J. C. Fabry, Analyst

TABLE 3

TOTAL SiO_2 ANALYSES FROM THE GIANT SYSTEM

1st level, 100 feet, Giant Mine

Sample No.	Description	Total % SiO_2
YC-10	Chloritized greenstone. Chip sample across 20 feet	44.86
YC-11	Chlorite schist, some chlorite-carbonate schist. Chip sample across 40 feet	46.07
YC-12	Carbonate-chlorite and carbonate-sericite schist. Composite chip sample across 20 feet	45.47

R. J. C. Fabry, Analyst, Samples YC-11 and YC-12
J. A. Maxwell, Analyst, Sample YC-10

3rd level, 425 feet, Giant Mine

Sample No.	Description	Total % SiO_2
YC-13	Greenstone, chip sample across 100 feet	47.25
YC-14	Chlorite schist, some chlorite-carbonate schist. Chip sample across 100 feet	45.48
YC-15	Carbonate-chlorite and carbonate-sericite schist. Composite chip sample across 20 feet	37.71

R. J. C. Fabry, Analyst

Figure 5 summarizes in a general diagrammatic manner the behavior of SiO_2 in all shear zones where the alteration zones are distinct. The first profile shows clearly that there is a consistent decrease in the SiO_2 content of the alteration halo as the quartz lenses are approached. The second profile shows a distinct loss of SiO_2 in the carbonate-chlorite portions of the shear zones when compared with the country rock and the chlorite schist phase of the shear zone.

TABLE 4

CHEMICAL ANALYSES OF ALTERATION ZONES
Negus-Rycon System

	YC-16	YC-17	YC-18
SiO_2	49.18	45.40	34.96
Al_2O_3	10.59	7.25	12.21
Fe_2O_3	7.20	3.56	3.01
FeO	9.87	9.16	8.93
CaO	11.01	10.99	10.42
MgO	5.63	4.18	4.40
Na_2O	1.16	.50	1.11
K_2O	.24	1.02	2.48
H_2O^+	1.46	3.26	.80
H_2O^-	.07	.14	.31
TiO_2	.84	1.05	1.79
P_2O_5	.18	.38	.70
MnO	.22	.11	.08
CO_2	1.39	9.56	12.13
S	.85	2.17	6.47
As_2O_3	.tr	1.57	1.93
Total	99.89	100.30	101.73
Less O/S	.31	.79	2.43
Net total	99.58	99.61	99.30
Specific gravity	2.97	2.85	3.01

R. J. C. Fabry, Analyst

Notes

YC-16 Greenstone, chip sample across 80 feet, 11th level Negus Mine, Negus-Rycon system.
YC-17 Chlorite and chlorite-carbonate schist, chip and channel sample across 2 feet, 11th level Negus Mine, Negus-Rycon system.
YC-18 Carbonate-chlorite and carbonate-sericite schist, chip and channel sample across 1 foot, 11th level Negus Mine, Negus-Rycon system.

Figure 6 and Table 6 show the results of a series of chemical analyses of samples taken across the total width of the alteration phases of the shear zone at different levels in the Con System. In this system the quartz lenses occur above extensive carbonated parts of the shear zones. The loss of SiO_2 in the shear zones compared with the greenstone increases with depth; at 500 feet it is 6 percent, at 1,400 feet it is 7 percent, and on the lowest level, 2,300 feet, it is 20 percent.

The profiles shown in Figure 7 are compiled from the chemical analyses of Table 4 and represent the chemical changes across a clearly defined altera-

TABLE 5

CHEMICAL ANALYSES OF ALTERATION ZONES
Campbell System

	YC-19	YC-20	YC-21
SiO_2	51.53	43.91	49.29
Al_2O_3	16.31	14.72	13.10
Fe_2O_3	.94	.30	1.21
FeO	9.65	6.87	5.67
CaO	8.59	9.43	7.99
MgO	6.23	7.69	3.81
Na_2O	2.49	1.63	.33
K_2O	.11	.70	1.59
H_2O^+	2.11	3.55	1.45
H_2O^-	.10	.46	.10
TiO_2	.84	.58	.26
P_2O_5	.22	.33	.14
MnO	.16	.22	.08
CO_2	.55	9.60	10.48
S	.28	.43	3.67
As_2O_3	—	—	2.87
Total	100.11	100.42	102.04
Less O/S	.10	.15	1.38
Net total	100.01	100.27	100.66
Specific gravity	2.95	2.75	2.94

R. J. C. Fabry, Analyst

Notes

YC-19 Greenstone, chip sample across 250 feet. 13 level Negus Mine, Campbell system.
YC-20 Chlorite and chlorite-carbonate schist, chip sample across 70 feet. 13 level Negus Mine, Campbell system.
YC-21 Carbonate-chlorite and carbonate sericite schist, quartz stringers and small lenses. Chip and channel sample across 2 feet. 13 level Negus Mine, Campbell system.

TABLE 6

TOTAL SiO_2 ANALYSES FROM THE CON SYSTEM

Greenstone	Shear Zone
Meta-andesite and meta-basalt	Chlorite schist, carbonate chlorite and carbonate-sericite schist composite
500 foot level	*500 foot level*
Channel chip sample across 60 feet	Channel chip sample across 15 feet
% SiO_2-44.0	38.0
1,400 foot level	*1,400 foot level*
Channel chip sample across 30 feet	Channel chip sample across 10 feet
% SiO_2-42.8	35.6
2,300 foot level	*2,300 foot level*
Channel chip sample across 40 feet	Channel chip sample across 20 feet
% SiO_2-49.0	29.0

Analyses, courtesy the Consolidated Mining and Smelting Co., Trail, B. C. Samples were obtained and submitted by Dr. C. G. Cheriton.

tion sequence adjacent to a quartz lens in the Negus-Rycon system. The main points of interest are the consistent decrease of SiO_2 and the concurrent increase in CO_2 as the quartz vein is approached. H_2O appears to increase in the chlorite and chlorite-carbonate zone and decreases in the carbonate-sericite zone. The combined oxides CaO, MgO, FeO, Fe_2O_3, and MnO show a slight decrease from the country rock but maintain a fairly constant value within the alteration zones. K_2O and Na_2O show an increase in the carbonate-sericite zone.

The principal mineral transformations inferred from the thin section study and chemical analyses are as follows.

To form the chlorite schist phase the amphibole, epidote, and plagioclase in the country rock in the presence of abundant H_2O and some CO_2 were broken down and altered to chlorite, albite, and small amounts of ankerite. Some SiO_2 was liberated.

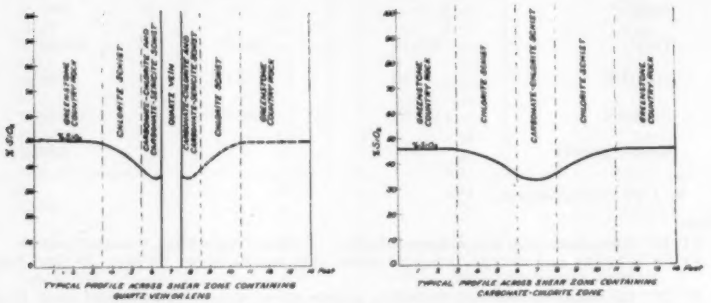

FIG. 5. Profiles illustrating the behavior of SiO_2 across the alteration zones.

In the formation of the carbonate-chlorite phase the introduced CO_2 attacked some of the chlorite and plagioclase, binding the elements Ca, Mg, Fe, and Mn into the ankerite structure and liberating considerable amounts of SiO_2. At the same time Na and K would be liberated from the disintegrated plagioclase structure. Similar reactions have taken place in the carbonate-sericite phase, but the principal feature is the reaction of K and Na with chlorite to form sericite. From the chemical analyses it is apparent that SiO_2 is liberated during the reactions that produced this phase.

An estimate of the amount of silica liberated during the alteration of the greenstone country rock to chlorite and chlorite-carbonate-sericite schist can be made from the analyses and geological mapping. Similarly a reliable estimate of the amount of quartz in the lenses and veins can be obtained from geological mapping. This has been done in considerable detail for the productive shear zone in the Negus part of the Campbell system based on the following data.

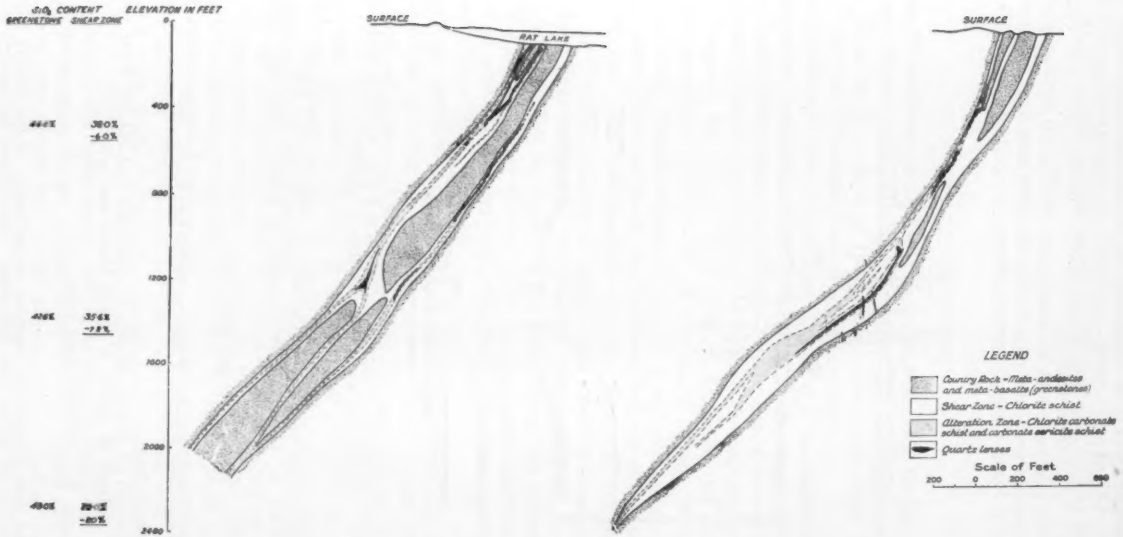

FIG. 6. Typical geological sections of the Con system showing relationship of alteration zones to quartz lenses and the marked loss of SiO_2 in the shear zones with depth. Con Gold Mine, Yellowknife, N. W. T.

Length of exposed schist zone	2,700 feet
Average true width of schist zone	250 feet
Vertical extent of exposed schist zone to lowest mining level	1,200 feet
Average loss in silica from analyses	5.0%
Average specific gravity of rock in schist zone	2.85
Number of cubic feet per ton of rock in place in schist zone	12.5
Number of cubic feet per ton of quartz in place	12.0

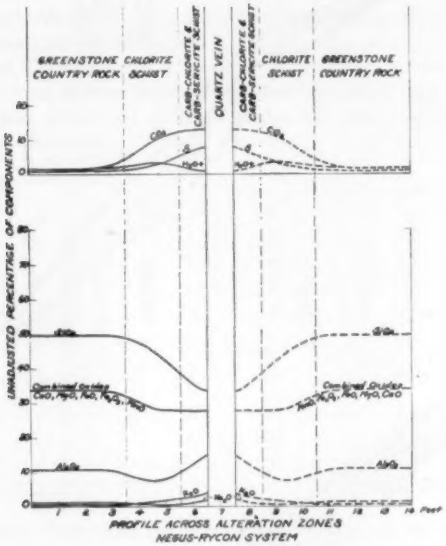

FIG. 7. Graph showing the percentage gains and losses across a well defined alteration zone. Negus-Rycon system.

The total volume of rock affected by alteration $= 2700 \times 250 \times 1200$
$= 810{,}000{,}000$ cu. ft. (less volume occupied by quartz veins and lenses $= 9{,}614{,}000$ cu. ft.[3])
$= \frac{800{,}386{,}000}{12.5}$ cu. ft. $= 64{,}030{,}880$ short tons

Total loss of SiO_2 in this weight of rock $= 64{,}030{,}880 \times \frac{5}{100}$
$= 3{,}201{,}540$ short tons
Therefore, the amount of quartz derived by alteration $= 3{,}201{,}540$ short tons.
Total calculated tonnage of quartz in quartz lenses and veins
$= \frac{9{,}614{,}000^{3}}{12}$ cu. ft. $= 801{,}160$ short tons

[3] This figure has been derived from mapping and estimation of the volumes occupied by both barren and ore-bearing quartz veins and lenses. This includes the quartz remaining in the shear zone after mining, as well as that removed from the stopes.

The above calculations and the discussion to follow assume that there has been no change in the volume of the rock during alteration. This assumption seems justified from field and laboratory studies, but even if there were small changes in volume the difference between the amount of SiO_2 liberated during alteration and that present in the known lenses is so great (nearly 4 to 1) that the general conclusions would be little altered.

DISCUSSION

From the evidence presented it seems probable that the SiO_2 in the quartz lenses was derived from alteration processes that took place within the shear zones. That is, the quartz of the quartz lenses came from the shear zone itself; it was not introduced from an outside source.

The calculations given above show that there is an ample source of quartz from alteration processes. There is no need to introduce silica from outside sources; instead the problem would appear to be how to account for the excess silica liberated during alteration and so balance the calculations.

The shape of the SiO_2 profiles (Fig. 5) indicates that the migration of SiO_2 was toward the present site of the quartz bodies. If silica had been introduced from external sources either as a siliceous melt or in magmatic solutions and diffused outward, the profiles across the alteration zones should be the reverse. The two possible cases are shown in Figure 8. There is certainly no chemical evidence to suggest that the SiO_2 was derived from any other source than that due to the alteration processes.

It is probable that the details of the formation of the quartz veins are exceedingly complex; they involve diffusion processes and complex chemical reactions of which little is known. However, with the evidence at hand the following process seems probable.

Migrating solutions carrying CO_2 in solution attacked the ferromagnesian and plagioclase minerals of the shear zone. They reacted with these minerals to form ankerite and liberated considerable amounts of SiO_2, K, and Na. The liberated SiO_2, K, and Na formed Na_2SiO_3 and K_2SiO_3 which are soluble in water and therefore capable of migrating in solution in an ionic form. Structural movement along the shear zones created low-pressure dilatant zones particularly at the junction of shear zones. The solutions containing the soluble silicates migrated laterally and upward toward these dilation zones where reaction between chlorite, plagioclase, Na, and K produced sericite and albite. This reaction precipitated the silica as quartz veins and lenses.

The writer suggests that the origin of quartz veins postulated in this paper probably is general for gold quartz veins in greenstones and similar rocks in other parts of the world. Support is found in the observations of other workers. Thus Lindgren (3) after a study of some gold ores from Western Australia where the lodes occur mainly in amphibolites concluded that the alteration processes in the amphiboles were as follows (page 539). "The metasomatic processes consist then in the introduction of carbon dioxide and sulphur with gold, mercury and tellurium and the attendant development of carbonates at the expense of the lime, magnesia and iron contained in the chlorite

and amphibole, and of pyrite at the expense of the same minerals and the black iron ores. The silica set free by the decomposition of the silicate has been deposited as quartz where it was not needed for the formation of the new silicates sericite and albite."

Finlayson (4), in his description of the alteration of andesite and dacite lavas and tuffs in the vicinity of the gold ore bodies of the Hauraki Gold fields, New Zealand, gives analyses of fresh and altered hornblende andesite which

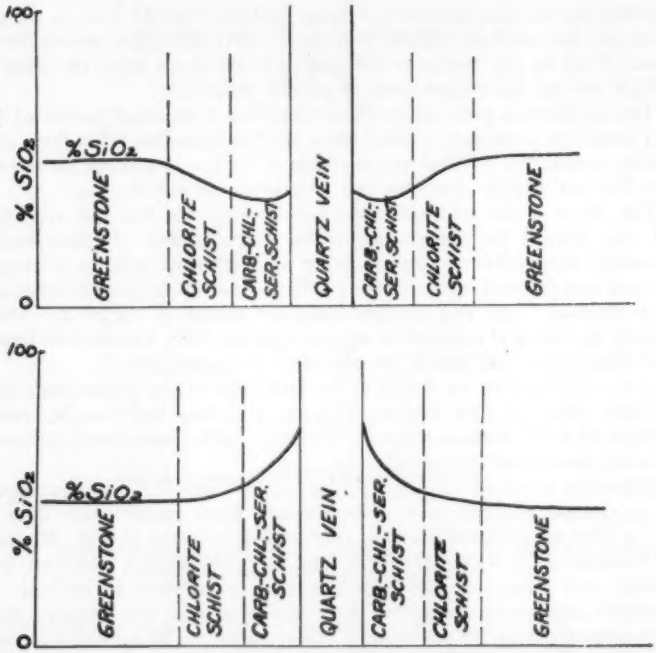

FIG. 8. (Upper) Actual percent SiO_2 profile across alteration zones. Profile suggests diffusion of SiO_2 toward present site of quartz vein. (Lower) Expected percent SiO_2 profile across alteration zones if SiO_2 had been introduced and diffused outward from present site of quartz vein.

indicate that during chloritization and carbonization processes silica is lost in the chloritized parts of the alteration zones.

Simpson and Gibson (5) give a series of analyses of typical Kalgoorlie rocks in which the propylites (chlorite-carbonate schist) and carbonated portions show substantial losses of silica as compared with the amphiboles, gabbros, and epidiorites from which they were derived. The analyses given by Feldtmann (6) substantiate the above conclusions. Analyses of a suite of

specimens from Ora Banda (40 miles N.W. of Kalgoorlie) given by Clarke and Ellis (7), however, show an increase in the silica content as the veins are approached. The specimens were, however, not in a complete sequence from one crosscut.

Moore (8) in a study of the alteration of a Precambrian granite at the St. Anthony Gold Mine, Sturgeon Lake area, Ontario, found a decrease in the amount of silica as the quartz veins were approached and concluded from the analyses (page 756), "a comparison of the analyses shows a regular decrease in the silica content of the granite indicating a transfer to the veins."

McCann (9) in his study of the gold-quartz veins of the Bridge River district, B. C. where the veins occur in augite diorite found a strong desilication of the adjacent wall rocks. He makes comparisons with the Grass Valley and Juneau, Alaska gold deposits and finds a similar phenomenon. About the silica he says (page 364), "the silica which has been lost has probably contributed to the vein filling. . . ."

Knopf (10) in his description of the Mother Lode system in California observed (page 47), "the carbon dioxide liberated immense quantities of silica from the wall rocks, and this silica was delivered to the vein channels, where it was in part precipitated as quartz."

At Porcupine Hurst (11) found that during the alteration processes of the dacite, pillow lava (greenstone), and quartz porphyry in which the ore bodies occur, the content of silica was decreased substantially in the altered equivalents of these rocks adjacent to the quartz bodies.

Bateman (12) describing the character of the wall rock alteration in the Uchi Lake greenstones gives analyses and remarks on the desilication of the alteration zones adjacent to the gold veins and orebodies.

Davidson and Banfield (13), describing the alteration associated with the Beattie gold deposits which occur in syenite porphyry and greenstones, give analyses showing a desilication of the syenite porphyry as the vein is approached. The andesite greenstone, however, shows an increase in silica as the orebody is approached. Only two analyses are given and it is difficult to draw conclusions. The andesite (dark greenstone) does not appear to be a normal sample of greenstone country rock since it contains 29.70 percent SiO_2 and 18.75 percent $CaCO_3$. It probably represents a stage in the alteration process.

After a study of the sixteen to one Gold-Quartz Vein, Alleghany, California, which occurs in a sedimentary sequence with serpentinite bodies, Cooke (14) suggested that the silica released as a result of chloritization, sericitization, and carbonatization from adjacent and deeper wall rock may have formed the vein quartz.

CONCLUSIONS

The chemical evidence and quantitative relationships strongly suggest that the quartz in the quartz veins at Yellowknife was derived by a carbonatization and chloritization alteration process within the shear zones. There seems to be no reason for postulating introduction of silica by magmatic solutions or injections of siliceous melts. In fact just the opposite appears to be the case,

namely, that a problem exists in accounting for the excess silica liberated during alteration over that present as quartz in the shear zones.

The origin of the gold-quartz veins of the type discussed in this paper appears to be a general one judging from the observations of several workers in various parts of the world.

GEOLOGICAL SURVEY OF CANADA,
OTTAWA, CANADA,
April 5, 1954

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THE GENESIS OF ASBESTOS IN ULTRABASIC ROCKS

P. H. RIORDON

ABSTRACT

The asbestos and picrolitic veins of the asbestos deposits in the Thetford-Black Lake District are very similar in structure and tend to grade into one another. Field and laboratory evidence suggests that the original vein serpentine was in an amorphous or nearly amorphous state, and that the veins are in many cases of a composite nature, resulting partly from fissure-filling and partly from wall rock replacement. It is proposed that the picrolite and asbestos were derived through crystallization of this vein material, and that two stages of crystallization were involved such that a first stage gave rise to picrolite and a second resulted in the conversion of picrolite to asbestos.

INTRODUCTION

DURING the past seven years the writer has had the opportunity of examining in some detail the asbestos deposits and their environs in the Thetford-Black Lake District of Quebec. In the course of the field work and laboratory investigation it became evident that none of the existing theories concerning the genesis of chrysotile asbestos were reconcilable with the conditions that pertain in this region. The purpose of this paper is to outline the various characteristics of vein serpentine and, in particular, those of chrysotile asbestos veins, and endeavor to draw certain conclusions as to the manner of formation of asbestos veins and asbestos fiber.

The writer wishes to express his gratitude to Dr. M. Archambault and Mr. Fernand Claisse of the Quebec Department of Mines for their X-ray and thermal analyses, and to the Deputy Minister of Mines, Quebec, for permission to publish this paper. He is especially indebted to Dr. J. E. Gill of McGill University for his advice and encouragement during the preparation of this paper.

VEIN SERPENTINE

The material of the veins that occur in the host rocks of the Thetford-Black Lake asbestos deposits displays a great variety of form, color, hardness, and texture. From a study of numerous hand specimens and thin sections of vein serpentine it is believed that most of it is fibrous. Certain varieties, that appear to be massive in the hand specimen, often grade into columnar material, and under the microscope, although some of this material appears to be amorphous, much of it has a fibrous form.

A description follows of the main types of vein serpentine considered to be peculiar to the host rocks of the asbestos deposits and to the late stage of serpentinization associated with the formation of these deposits (3).[1] These include asbestos veins, picrolite veins, and serrated veins.

[1] Numbers in parentheses refer to References at end of paper.

Asbestos Veins

Most of the asbestos veins in the Thetford-Black Lake area are composed of cross-fiber; however, a good deal of slip-fiber may occur in conjunction with the cross-fiber or in zones where the deformation has been more intense.

The characteristics of the cross-fiber veins are tabulated below for purposes of easy reference. These data are based on the observations of Cirkel (2), Dresser (4), Graham (7), Harvie (6) and Cooke (3), as well as on those of the writer:

(a) *Widths*—range up to four inches; however these are rare and most veins are under three-eights of an inch.

(b) *Form*—minute gash veins, or lenses, or persistent veins up to several tens of feet in length. They may be straight, curved or irregular. They may intersect, branch or have minor offshoots.

(c) *Color*—normally shades of apple-green to dark green and olive-brown, which is generally constant across the width of the vein, and commonly approaches the color of the wall rock.

(d) *Fibers*—silky and soft, to harsher varieties that generally have a higher content of iron and lower content of water (3). They are parallel, and may lie normal to the walls of the vein or occupy any position between this and parallel to the plane of the vein, but generally lie somewhere between vertical and normal to the vein wall. They are rarely perfectly straight, and normally display minute corrugations, some of which may be pronounced. These corrugations may be persistent along the vein but individually may fade out to be replaced by others, or may coalesce; they give the vein a banded appearance (Fig. 4).

(e) *Partings*—one or more may be present and are generally parallel to the vein but are commonly irregular. The orientation of the fibers is generally the same on either side of a parting.

(f) *Magnetite*—occurs along the partings as fine grained sheets or lenses. These are seldom continuous, normally display extreme irregularities, and may occupy any position in the vein, although they tend roughly to parallel the walls. Some disseminated grains may be present, and strings of magnetite in places are parallel to the fibers. Magnetite is usually abundant in the wall rock immediately adjacent to the vein, and in inclusions.

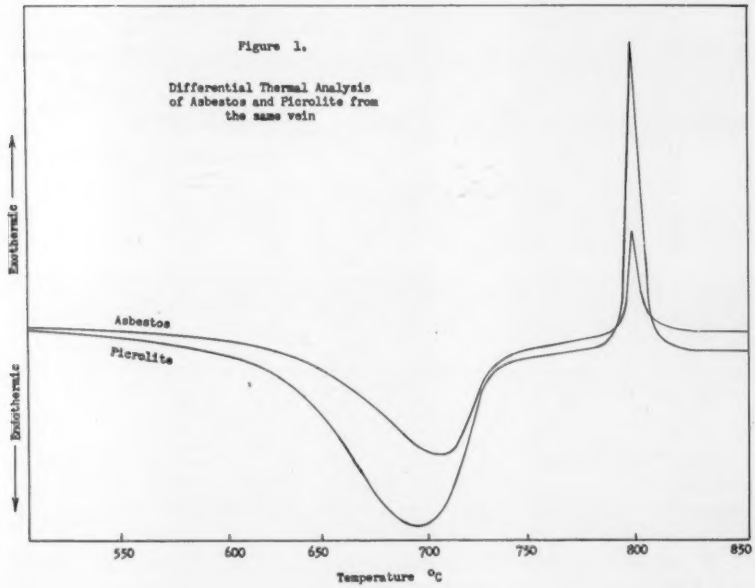
(g) *Walls*—are commonly sharply defined; minute irregularities are normal. Some veins have distinctly crenulated margins suggestive of some replacement. Major irregularities in opposing walls can normally be matched. In some cases one wall may be slickensided and coated with picrolite. Vein material may separate more readily from one wall than the other.

(h) *Inclusions*—of wall rock take the form of thin selvages or angular fragments. Many, although not all, of these match irregularities in the wall. Some have evidently been displaced along the vein. Inclusions of picrolite may be present; some of these may run oblique to the vein, which is thus broken up into a series of en echelon lenses.

(i) *Intersections*—the fibers of both veins may tend to coalesce, or there may be a confused mixture of magnetite, picrolite, and asbestos. Cross-cutting veins are extremely rare. Junctions are commonly marked by the presence of much magnetite. At some intersections the fiber of the marginal portion of one vein may be seen to swing around the corner to merge with the fiber of a similar portion of the other vein.

(j) *Displacement*—post-asbestos faulting is not common, and is generally very local.

(k) *Gradations*—asbestos may give way to picrolite either laterally, or along the length of the vein, and in places appears to lens out (Fig. 12). Veins may terminate abruptly, or fade out into wall rock, without any gradual decrease in width.



Picrolite Veins

A common variety of fibrous material that occurs along fault planes, and particularly in those associated with the blocky type of ground in which asbestos veins so often occur, is slip-fiber picrolite. This material is made up of bundles and sheaves of coarse fibers that lie roughly parallel to the plane of the fissure. It is generally soft, and white to pale yellowish green in color, and has a splintery fracture. The fibers separate with difficulty, and

generally break easily. This material grades into apple green and darker shades of a harsh, compact, brittle form that, nevertheless, may be seen to be fibrous when observed in thin sections.

A cross-fiber variety of picrolite is found in the form of compact veins that have a banded structure parallel to the walls and a columnar structure normal to the walls. These veins range in size from microscopic veinlets up to as much as several inches in width. In some cases they are dark green, or assume the olive brown color so typical of the serpentinized host rock. They generally have a waxy luster, and although some are quite hard and compact, others are surprisingly soft, and may be mistaken for talc. The softer varieties appear to have a high content of uncombined water, since they tend to lose weight and crumble after brief exposure to the atmosphere.

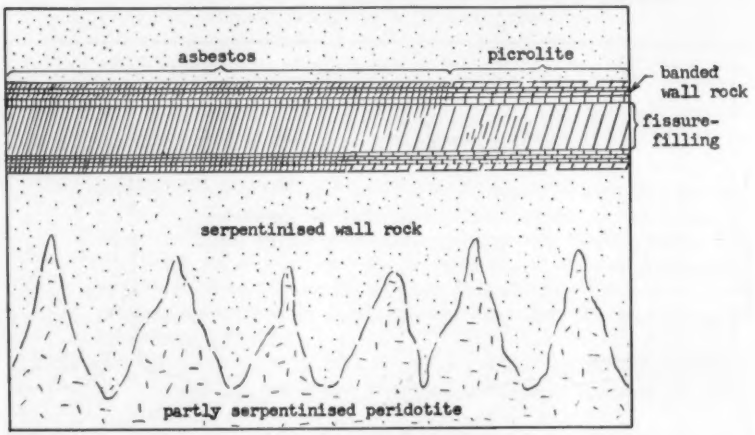


FIG. 2.

These banded veins are associated with fault planes, and many other fissures similar to those with which asbestos is normally found. Cooke (3) referred to them as "painted veins" because of their similarity in appearance to asbestos veins, for which they may at first be mistaken.

In polished specimens the delicate bands paralleling the walls are mostly only a small fraction of a millimeter in thickness but may reach as much as several millimeters (Fig. 3). The parting between successive bands is generally sharp and the banding is further emphasized by slight differences in color. The bands are rarely perfectly straight, but reflect the irregularities in the vein wall and are slightly corrugated or wavy. The banding does not in all cases extend across the full width of the vein, and may be confined to the margins of the vein, or to one margin only.

In thin sections individual bands may be seen to have more or less simultaneous extinction (Fig. 5), and appear to be composed of transverse, parallel

fibers that occupy a position anywhere from normal to noticeably oblique to the margins of the band. The position of extinction, which differs in alternate bands, is evidently due to slight differences in the orientation of the fibers in successive bands. In some bands, sweeping extinction occurs transverse to the band and is apparently due to curvature of the fibers within a band. In some cases the fibrous structure may be continuous across several bands, whose

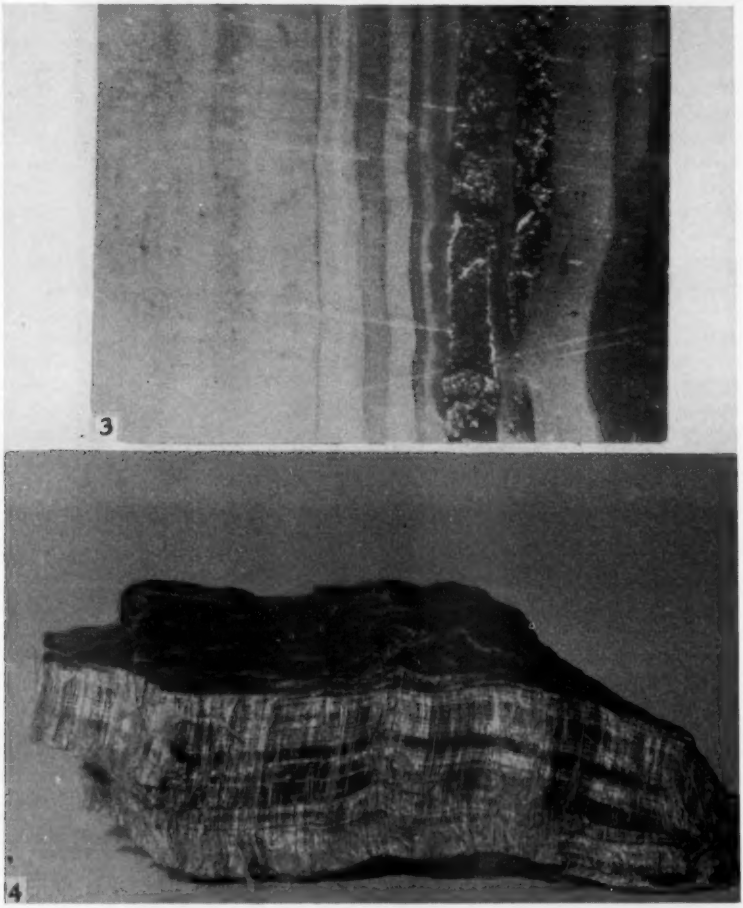


FIG. 3. Delicately banded wall rock portion of a composite picrolite vein; black bands are mainly magnetite (reflected light, × 18).

FIG. 4. Delicate banding in an asbestos vein (natural size).

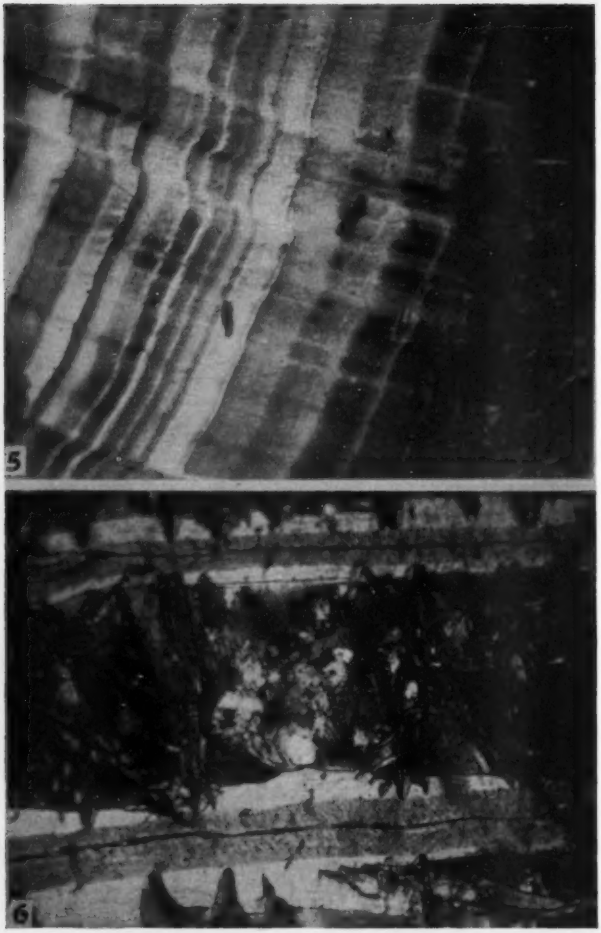


FIG. 5. Banded portion of the same vein as Fig. 3. Vein margin fades out into nearly isotropic serpentine (right). Note the fibrous structure transverse to banding. The original compositional partings between bands are emphasized by what are probably discontinuities or sharp flexures in the fibrous material (X Nicols, × 18).

FIG. 6. Composite picrolite veins cut serpentinized dunite. The primary veinlets terminate in the marginal banded portions (white), which are evidently replaced wall rock in contrast to the central portions (gray), which are probably fissure-filling. The center of each vein carries a string of magnetite. The material of the veins is fibrous with a common orientation in the banded portions (X Nicols, × 60).

apparent margins are marked by what are presumably sharp kinks in the fibers. In one unusually compact specimen of banded vein material, individual bands were distinct between crossed nicols and appeared to be composed of cryptocrystalline serpentine with slightly coarser and more birefringent material along the partings, suggesting an early stage in the evolution of the more crystalline fibrous varieties.

The structure of these veins may be emphasized by the yellowish cloudy character of certain bands, or by the presence of a little fine grained brucite in some bands, and its absence in others. Furthermore, they commonly display a composite form (Fig. 6) wherein the banding is confined to the walls, and the central portion stands out in sharp contrast. The outer margins of the banded portions tend to fade out into the wall rock, which may be composed of relatively unaltered olivine, but, in the case of the larger veins, is composed of isotropic serpentine with abundant disseminated magnetite. The whole of the central and banded portions is composed of transverse fibers, but there is often a marked difference between the orientation of the fibers in the central portion and those in the margins. The orientation in the marginal zones is generally common to both sides of the vein. An almost continuous string or sheet of magnetite generally occupies the center of the vein, and lenses sometimes occur within the banded portion.

Where the veins cut the primary or autometasomatic serpentine veinlets, the latter fade out within the banded margin (Figs. 6, 7). Where two composite veins cross one another the banded portions of the two veins merge at the junction, whereas the central serpentine portions are broken up into a number of irregular fibrous segments. It is evident, therefore, that the banded portions represent replacement of the walls whereas the central portion is probably "fissure-filling."

Not all of the fissure-fillings are accompanied by banded margins. Some grade along their length into amorphous serpentine or material that is slightly but irregularly anisotropic and probably cryptocrystalline. Many of the smallest veins, none of which have the banded margins, are composed of amorphous serpentine. Other veins have the normal central portion of transverse fibers accompanied by amorphous margins, which appear to be replacement of the original walls.

The margins of those veins, which are composed of amorphous serpentine, or banded fibrous serpentine grading into amorphous serpentine, suggest a form of colloidal "replacement," and it is evident, from the amorphous nature of some of the vein-fillings, that these probably resulted from colloidal deposition. The cloudy nature of some of the vein-fillings and bands is thought to be due to the deposition of iron from a colloidal stage. Furthermore, analyses show that the content of uncombined water in these veins is considerably higher than that of the normal wall rock serpentine (3).

Both the compact slip-fiber and cross-fiber varieties of picrolite may be found in the same vein. A thin section containing both these materials, when observed in ordinary light, was completely featureless, and the difference in form was only revealed between crossed nicols. The slip-fibers form a twisted mass, more or less, parallel to the vein walls in contrast to the transverse structure in the banded portion.

The various characteristics of these picrolite veins suggest that they probably had a colloidal origin, that the initial solid phase was amorphous or cryptocrystalline, and that, at some later stage in the process of their evolution, this material, in most cases, assumed a fibrous form.

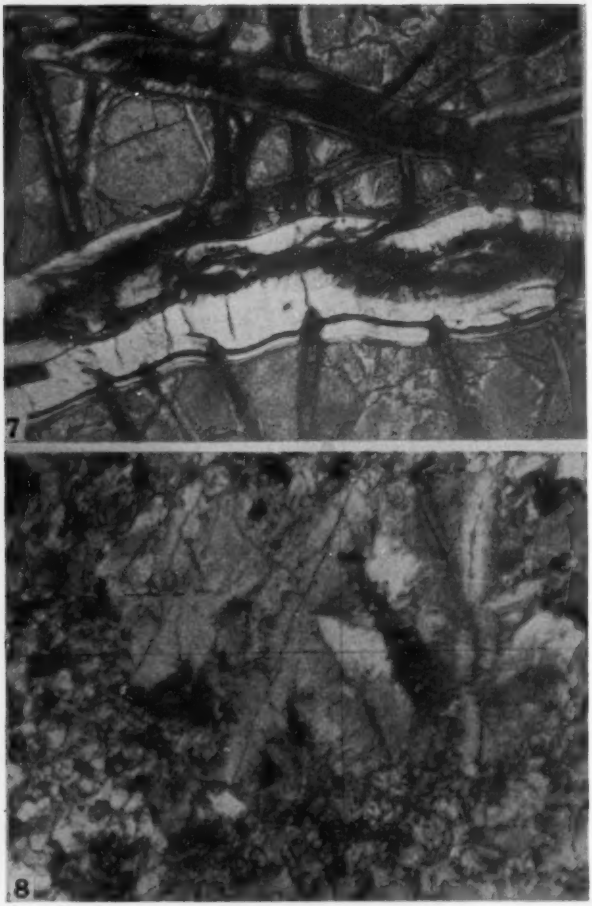


FIG. 7. Picrolite veins cut partially serpentinized olivine. The primary veinlets fade out in the banded marginal portion of the later larger veins. Black material in the larger veins is magnetite which is mostly confined to the central portions (X Nicols, × 60).

FIG. 8. Fibrous (to bladed) serpentine in serrated replacement veins; the fibers (or blades) extend outward from minute, irregular fractures (X Nicols, × 18).

Serrated Veins

In thin sections of the host rocks a fibrous variety of serpentine may be observed on either side of a central fracture. This fibrous growth is roughly normal to the plane of the fracture and produces a microscopic vein with sharply serrated margins (Fig. 8). A proportion of the vein material may appear to have a bladed form, and in some cases this variety seems to be the sole constituent. The fibers are not always perfectly parallel, but have more or less simultaneous or sweeping extinction along the length of the vein. The fractures, associated with these veins, are mostly irregular, and it is evident from the relationships to be found that the fibrous, or bladed, serpentine has replaced the walls. Some of the fractures may have a thin filling that is composed of serpentine, of a very low birefringence, and a little magnetite.

Not uncommonly this vein material has a noticeably high birefringence and it is possible that some of it is actually chrysotile. Successive veining is common and in some cases the fractures may be sufficiently closely spaced to have allowed for almost complete replacement of the original material of the rock. Branching and intersecting veins produce an effect somewhat similar to a dendritic pattern.

ORIGIN OF ASBESTOS VEINS

The hypotheses advanced to explain the origin of asbestos veins fall into two main groups, those in each group differing from one another on minor points only. One hypothesis is that the fibers have grown between the walls of the original rock fracture; Taber (13), Keith and Bain (11), Keep (10), and Cooke (3) have supported this view. The other is that the fibers grew at the expense of the walls of the original fracture; Dresser (4) and Graham (7), (8) are the chief proponents of this view.

The process involving growth of asbestos fibers between the walls of the fissure, as generally accepted, requires that the fissure walls separate as the fiber grows. This hypothesis could only be satisfied by a gradual separation of the walls. It might be expected, however, that this movement, in most cases, would be rapid or sudden, such that the walls would have assumed their present position immediately the rock fractured. The only other alternative, therefore, would be for the asbestos fibers to have grown outward into the open space from one or both walls. Split cross-fiber veins are common; however, if growth had occurred simultaneously and independently from both walls it seems improbable that the fibers on both sides would have assumed the same inclination to the vein walls, which is the rule, except for minor corrugations. If the original fibers are to be envisaged as having grown perpendicular to both walls, then later deformation would have to account for the deviations that occur, and certainly there is little evidence in these compact veins which would support this view.

The theory that postulates the formation of asbestos exclusively beyond the walls of the fissure would require that the fissure was never open, or, at least, that the opening was only microscopic. Again this is contrary to what might be expected to occur in the case of normal fracturing associated with faulting.

Although many fissures might remain closed, it seems inevitable that the majority would produce openings. This situation would almost certainly develop as a result of movement along an irregular fault plane.

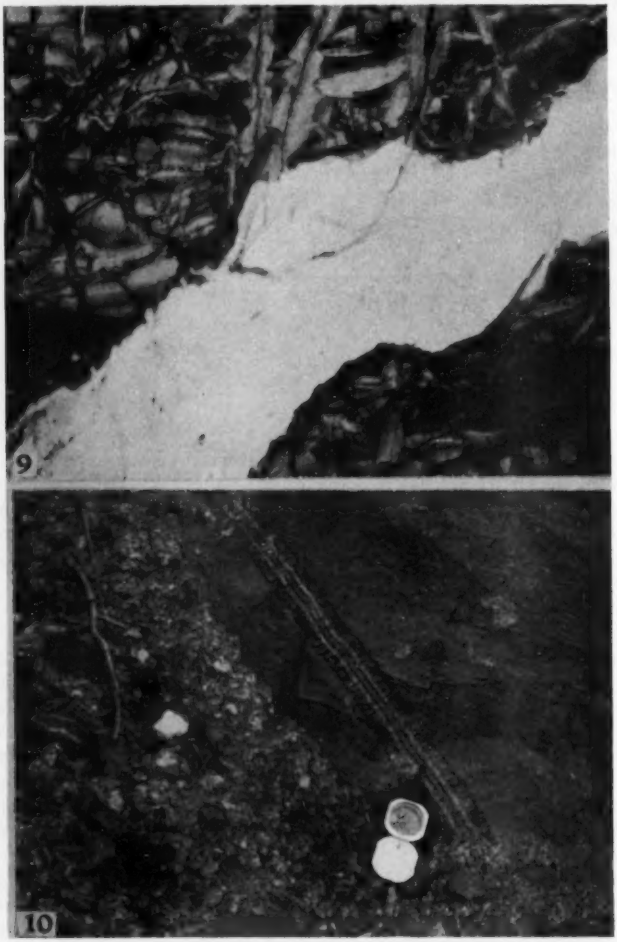


FIG. 9. Asbestos vein with what appear to be "ghosts" of the wall rock structure preserved along the upper margin. Note also the "matching" irregularities in either wall, and the faint central parting—or what may represent the position of the original fracture (X Nicols, × 18).

FIG. 10. Asbestos vein (central band at tip of compass arm) and marginal zones of serpentinized wall rock.

The general characteristics of the asbestos veins, enumerated earlier, suggest that fissure-filling has occurred. In places, minor unmatched irregularities in the walls, and the presence in the vein margins of what appears to be relict wall rock structure (Fig. 9), would indicate that there has been some growth at the expense of the walls. It seems probable, therefore, that both processes

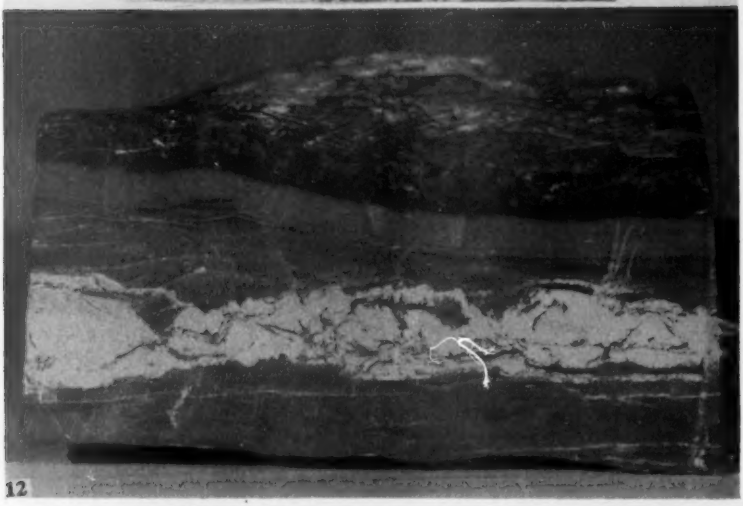


FIG. 11. Composite asbestos vein. Fibers in the broad central portion lie at a flat angle with the walls, whereas those in the banded margins are less oblique and the orientation is similar on either side (X Nicols, × 60).

FIG. 12. Polished section of a part of a composite serpentine vein. Asbestos (white) is bounded on either side by slip fiber picrolite. The upper delicately banded, marginal portion is composed of cross-fiber picrolite. The cross-fiber structure of the asbestos has been masked by polishing (× 2).

have been involved and that one or other may predominate in any particular vein.

One of the commonest characteristics of the asbestos veins is that, in many places, they may be seen to be composed of both picrolite and asbestos, and the relationships are distinctly gradational (Fig. 12). Pure asbestos veins do not necessarily lens out, but rather fade out into an intimate mixture of the two vein materials. Where asbestos does not occupy the entire space between the vein walls, the asbestos vein, itself, is commonly extremely irregular in outline. These conditions have been observed by the writer in the process of logging many thousand feet of vein-bearing drill core, and it is common knowledge to those who have been confronted with the task of assessing the asbestos content of the rock, that such relationships pose one of the most difficult problems.

It is evident from the character and relationships of the asbestos veins that they are the latest product of serpentinization, and that the asbestos was formed, for the most part, after all of the adjustments associated with this process had been completed. In view of the fact that the asbestos veins grade into picrolite veins and contain inclusions of picrolite, these two minerals might be presumed to be contemporaneous. However, these two products differ markedly in their physical properties and it seems more probable that they were formed under different conditions of temperature and pressure. One must therefore have been formed prior to the other, or one may have been derived from the other. The latter assumption is accepted as a basis for the hypothesis of asbestos genesis set forth in the following pages.

GENESIS OF ASBESTOS

Source of Vein Material.—The relationship between breadth of serpentinized vein margin and width of serpentine vein would suggest that the magnesia and a part of the silica [1] of the vein material were probably derived from the wall rock. That the vein material has largely been derived from the immediate walls is borne out by the fact that the composition of the picrolite and asbestos veins generally reflects the wall rock composition. This is particularly noticeable in the harsh dark-green to dark-brown fibers found in the serpentinized aureoles adjacent to the acid intrusives, where the content of iron is abnormally high. The gradual decrease in asbestos, and high content of quartz, in the asbestos veins that enter syenite bodies, also bears evidence to the influence of the immediate wall rocks as a source of the magnesia for the vein filling. The transporting power of the solutions was weak in the case of magnesia, for although some talcification of the quartzite has occurred over a narrow zone of a few inches beyond the contact, and serpentine and talc may be found over somewhat greater widths in the contact slates, these materials are virtually absent in the country rocks beyond the immediate contact, where, however, large quartz veins are numerous.

The process of serpentinization of the immediate wall rock of the fissure evidently involved, in some cases, successive advancing waves of replacement

[1] Assuming that the serpentinisation involved no change in volume, silica would be removed in addition to magnesia in the ratio of between 1 : 3 and 1 : 4.

by colloidal material. Removal of magnesia and some silica would accompany this process and the general serpentinization of the outer wall rock. It is suggested that this leached material accumulated in the fissures and in the final stages was deposited along with additional silica to form an amorphous vein-filling.

Commencing with this composite form of vein material, including part fissure-filling and part wall-rock serpentine, the successive steps leading to the formation of asbestos are postulated below.

Crystallization—1st Stage.—This stage involved the formation of cross and slip-fiber picrolite. Crystallization of the banded material of the wall rock probably preceded that of the vein-filling, as a sharp boundary invariably exists between the margins of the two, at which the transverse fibers terminate. During the crystallization of the serpentine of the amorphous banded wall rock, and of the fissure-filling, iron was thrown out. The tendency of magnetite to occupy the center of the vein would suggest that the fibers of the vein-filling, in most cases, grew inward from the original fissure walls. The concentration of magnetite in the wall rock beyond the banded portion would suggest that the iron in this case was either driven out during the initial period of serpentinization, or by the crystallization of this portion.

Although the fibrous material would tend to crystallize with its long axis normal to the vein wall (13), the direction would be influenced by vertical relief of stress and the position assumed might be expected to be somewhere between the vertical and normal to the vein wall. Small components of stress parallel to the plane of the vein would account for the deviation from layer to layer and within any one layer of the banded wall rock. The general attitude of the fibers in the central portion of the vein coincides with that of the fibers in the margins and it may be assumed that their growth was influenced in the same manner. Shearing stresses along the vein have resulted in the formation of a confused and twisted mass of fibers roughly parallel to the vein. This latter development, in places, is confined to one margin of the vein, to the center, or occurs in several portions of the vein. Alternatively, small oblique shears have given rise to fibrous growth parallel to these planes, which has tended to split the vein into a series of overlapping lenses.

Crystallization—2nd Stage.—Turkevich and Hillier (14) and others (1), through the use of the electron microscope, have illustrated the fact that chrysotile asbestos is probably tubular in form. It is not known whether picrolite exhibits the same characteristics; however it is clearly evident that these two products have very distinctive physical properties, the chief of these being the marked difference in tensile strength. Selfridge (12) has classified picrolite as a variety of antigorite; however powder X-ray photographs of the picrolite vein material from Thetford are closely similar to those of asbestos. Differential thermal analyses, on the other hand, do show a distinction between these two materials such that both the endothermic and exothermic reactions are noticeably more pronounced for picrolite in contrast to those of chrysotile asbestos (Fig. 1).

It is assumed, for lack of adequate evidence to the contrary, that the picrolite does not have the tubular structure attributed to chrysotile asbestos,

and that, therefore, an asbestos fiber would tend to occupy a somewhat greater volume than that of an equivalent fiber of picrolite. It is suggested, therefore, that the conversion from picrolite to asbestos would involve an overall increase in volume, and that such a change of state would be favored by conditions of tensile stress.

There is some evidence to show that the formation of asbestos veins was favored by tensile stresses. Cooke (3) has described the presence, in the serpentinized wall rocks, of tension cracks that are approximately normal to the plane of the asbestos vein. In the vein margins it is quite evident that serpentinization has worked outward from the walls, and, although the outer boundary is normally sharp in outline (Fig. 10), weathering of these margins reveals that the complete serpentinization fingers out into the partly altered rock (Fig. 2).

Cooling of the vein and walls would induce contraction; tension cracks in the walls would tend to follow the lines of weakness engendered by the alteration, such that the maximum strain developed roughly parallel to the plane of the vein. On the other hand, relief of stress within the vein itself could have been accomplished by the conversion of the picrolite to chrysotile.

The fibrous form of the serpentine in the composite picrolite veins would tend to lend itself readily to conversion into asbestos cross-fiber. The formation of asbestos would, therefore, merely involve some recrystallization and growth of the existing fibers across the full width of the vein or a part thereof. The minute corrugations, so frequently found at the margins of asbestos veins (Fig. 11) and over much of the widths of some veins (Fig. 4), are no doubt derived from the slight changes in orientation that prevailed in the original fibrous material in the adjacent layers of the wall rock (Fig. 2). The formation of slip-fiber asbestos from the slip-fiber picrolite, formed originally through shear stresses, would be accomplished at the same time and in the same manner as the formation of the cross-fiber asbestos.

The absence of asbestos in many of the picrolite veins, particularly around the margins of the deposits, could be interpreted on the basis that the initial temperatures were insufficient to cause the necessary stress conditions that prevailed within the main body of the deposit during cooling. It is apparent from the measurements, obtained by Cooke (3), of the serpentinized margins of these barren veins, that the conditions were not the same at the extremities of the deposit, and that serpentinization of the walls was noticeably less intense. The comparative absence of picrolite, particularly in the larger veins, and the absence of large picrolite veins, may be accounted for by the fact that circulation of solutions within the larger veins has been much greater than in the smaller. Consequently, the temperature would have been appreciably higher in the wall rocks of the larger veins, and the stress conditions would be much more favorable to the complete conversion of picrolite to asbestos.

It may be generally stated that the high temperatures that prevailed at the culmination of vein deposition, and the low confining pressures that existed during the cooling period, were the chief factors favoring the formation of asbestos. The presence of the larger bodies of acid intrusive, chiefly in the form of granite, has no doubt been to a large extent responsible for the higher

temperatures. In the absence of such bodies, the presence of through-going structures that served as main trunk conduits for the heat-bearing siliceous solutions has served a similar purpose.

SUMMARY

Brecciation of the host rocks produced the many fissures through which siliceous solutions circulated and caused serpentinization of the wall rocks. The wall rock in some cases was converted into colloidal serpentine over narrow widths. The magnesia and silica, removed during this process, was deposited in the fissures in combination with more silica in the form of colloidal serpentine. All of this colloidal serpentine later crystallized to form picrolite, largely transverse to the direction of the vein.

Chrysotile asbestos was derived from the picrolite of the preformed composite veins, as a result of recrystallization during the cooling stage subsequent to the formation and primary crystallization of these veins. These successive stages of crystallization would have served to mask the effects of successive fracturing and vein formation that inevitably occurred during the initial period of any fissure-filling that took place.

Heating of the fissure walls and host rock generally has been an important factor insofar as asbestos formation is concerned. Where temperatures were adequate to induce sufficient contraction during the cooling period, stress conditions were favorable for the recrystallization of the picrolite into asbestos.

The serrated veins are believed to be composed of antigorite, and were probably formed through replacement of the original serpentine of the host rock under conditions of dynamothermal metamorphism as proposed by DuRietz (5) and Hess, Smith and Dengo (9).

THETFORD MINES, P. Q.,
March 9, 1954

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DISCUSSION

ORIGIN OF THE ROAN ANTELOPE COPPER DEPOSIT OF NORTHERN RHODESIA

Sir: In the September–October issue (pp. 575–616) of ECONOMIC GEOLOGY there is a paper on the Roan Antelope Mine and reference is made to an earlier article by Garlick and Brummer. There have also appeared articles and discussions on the genesis of the Northern Rhodesian copper ores in the Bulletin of the Institution of Mining and Metallurgy. The authors have advanced arguments for a sedimentary origin of the copper ores. As I understand the argument it is as follows: The ancient schists were intruded by granite and mineralization accompanied the closing phases of the granite intrusion. Weathering and erosion followed and the sediments of the Mine Series were laid down in depressions adjacent to the areas being eroded. The copper minerals were carried down and deposited at the same time partly as a result of biochemical processes.

Folding and metamorphism followed this deposition and the last event was igneous activity in the form of gabbro intrusions.

The authors repudiate the earlier contention that there was a granite which cut the Mine Series. I was on the copper belt for part of 1929 to 1931 and saw most of the deposits in Northern Rhodesia and the Haut Katanga. I had the pleasure of driving Dr. Schneiderhöhn from N'Dola to N'Kana and on to N'Changa, so I heard a good deal about syngenetic ores from him. My own views at that time were definitely on the side of those who postulated an epigenetic origin, and there were many lively discussions with Bancroft, Gray, Davidson, Bateman and Grout, who all held that the ores were epigenetic. I should like to point out the difficulties that those who advocate the sedimentary hypothesis will have to explain.

First—Bancroft always stressed the importance of drag folds as being associated with the ore zones. This association seemed to be remarkably exhibited at N'Kana, N'Changa, Chambishi, and at the Roan Antelope. If these ores are epigenetic they are found in those places exactly where they should be.

For those who favor sedimentation it will be necessary to explain this strange fact, that the drag folds occurred where the ore had previously been deposited.

Secondly—There is no possible way to explain the Kipushi Mine where the ore occurs between the faulted ends of the Série des Mines and the fault plane, by an appeal to washed in sediments. I have still some of that remarkable ore in our museum.

The character of the ore in the River lode at N'Changa in my opinion is clearly epigenetic where veinlets of copper minerals run up along the shales

and cross from one shale bed to another. The recent authors attempt to explain this jumping of the beds by an appeal to metamorphism. It is a difficult task.

Thirdly—From polished sections and from various places underground which I saw, some twenty years ago, replacement was apparent.

Fourthly—The Mine Series consists of sediments that range from conglomerates and arkoses at the base to shales and dolomitic shales at upper horizons. The copper minerals are found in the shales. If the cupreous minerals are derived from a previous mineralization by erosion and transport, it seems very curious that these minerals are not with the coarse basal sediments but are associated with the mudstones on a higher horizon. The grain sizes given by Graton in a report in possession of the Roan Antelope Mine are as follows:

Relatively few grains	0.60 mm.
Average grain	0.06 mm.
Very many as small as	0.006 mm.
Many as small as	0.0025 mm.

If the average grain diameter of chalcocite is 0.06 mm. the average grain of the detrital quartz associated with it should be 0.08 mm. In other words the grain size of the sediments should be larger than that of the copper minerals which is not the case. The average grain size of sediments of the type of the Roan Shales is 0.01 mm.

If the chalcocite or chalcopyrite is the result of sedimentary processes these minerals should have been found in the conglomerates or arkoses at the base of the Mine Series. Those who favor a sedimentary origin have therefore to explain why they are in the mudstones well above the basal beds.

Fifthly—The statement that *all* the granite is older than the Mine Series is open to dispute. In my opinion the N'Changa granite is younger. The evidence is two-fold: At the nose of the syncline there is a tongue of granite or pegmatite cutting into the beds.

In the footwall rocks of the long crosscut to the first shaft which was put down in 1930 or 1931 the felspathic sandstones as I remember them show progressive felspathization, i.e., granitization as the granite is approached.

Far be it from me to discourage ideas—but hypotheses are tools not creeds, and those who advance ideas must be prepared to defend them.

My testament regarding the copper belt is therefore as follows: The ores are hypogene and epigenetic and were introduced into the sediments after those rocks had been mountain built and intruded by igneous rocks.

Tot homines quot sententiae.

G. VIBERT DOUGLAS

DALHOUSIE UNIVERSITY,
HALIFAX, CANADA,
Nov. 15, 1954

REVIEWS

Geology of Australian Ore Deposits. A Symposium arranged by a Committee of the Australasian Institute of Mining and Metallurgy. Edited by A. B. Edwards. Pp. 1290. A.I.M.M., 399 Little Collins Street, Melbourne, 1953.

This fat tome, about the size of Who's Who, published on the occasion of the Fifth Empire Mining and Metallurgical Congress is a fitting companion to "Structural Geology of Canadian Ore Deposits" to which it is in no way inferior. In general plan, it is similar in that the arrangement is geographical and that a summary of the geology of each region, written in most instances by a government geologist, is followed by descriptions of individual mines and districts mostly by "company" or consulting geologists.

While the collection of 135 articles covering all of the important metalliferous deposits of Australia [1] together with many that are less productive but of local or geological interest, constitutes an indispensable guidebook for anyone visiting Australian mines, its value goes far beyond this; it is a treasury of examples covering a wide range of structure and mineralization, providing rich source material for students of ore deposits regardless of their interest in Australia itself.

The introductory articles on the mineral resources of Australia (by H. G. Raggatt) and their tectonic setting (by E. S. Hills), along with the discussions introducing the chapters on the respective regions, constitute collectively an up-to-date summary of the geology and mineralization of the continent. When compared with the knowledge existing a quarter of a century ago they reveal notable advances and in some cases, quite revolutionary changes in interpretation. Thus, for Western Australia, the articles by Forman and by Miles recognize that the bulk of the "older Greenstone" is of volcanic rather than intrusive origin and that the associated "jasper bars" are sedimentary iron formations. This has brought about a revision of chronology, involving, among other things, the abandonment of an age of pre-greenstone sediments (the Yilgarn Series). While the reviewer would fain believe that this revision stems from his own advocacy of these views in 1933–5 against considerable skepticism at the time, it is clear that their ultimate adoption is the result of subsequent detailed studies by Ellis, Miles, Prider and others.

Another evident change wrought by the past quarter century is the increase in the number of geologists in the employ of the mining companies and, what is even more important, the excellent quality of their work. Especially in the interpretation of structure, the typical article is probably superior to the general run of contributions offered on the North American side of the Pacific and some of the studies are outstanding. They are illustrated by excellent plans and sections, some of them in color and most of them drawn to scale (not just generalized or idealized). While a few time-honored favorites are reproduced, the greater number are fresh, up to date, and not previously published.

[1] The only notable exception is the sensational uranium occurrence at Rum Jungle. Presumably information about it was either insufficient or still "classified" when the book went to press.

Since limitation of space would preclude a discussion of all of the articles (even if the reviewer could pretend to have read each of the 1290 pages) some comments on a few of the most famous districts will have to suffice.

Kalgoorlie.—In this most productive of Australian gold deposits attention has naturally centered on the rock unit known as quartz dolerite or "younger greenstone," the host of most of the minable lodes. Readers acquainted with this district will recall that a principal feature of Gustafson and Miller's "Kalgoorlie Geology Reinterpreted" of 1937 was the thesis that the dolerite sill had been folded along with its enclosing rocks. But perhaps for the reason that the shape of this (or almost any other) intrusive body can always be accounted for without recourse to subsequent deformation, the folding idea had not been adopted previously nor does it appear to have been universally accepted since, although to this reviewer it has always seemed the only plausible explanation. Thus, Campbell, in the present volume, takes mild issue with this phase of the "reinterpretation," and states that evidence (which may be perfectly valid but is not presented) suggests that "the quartz diorite was intruded . . . at some stage during folding, possibly at a late stage." He grants, however, that this point is not of critical importance in the structural interpretation. His main modification of Gustafson and Miller's structure is to show that west of the Golden Mile the quartz dolerite, instead of extending northward to form the west limb of an anticlinorium, continues toward the south (or would do so if not interrupted by faulting). Thus the main Kalgoorlie field instead of occupying the crest of an anticlinorium becomes merely a huge drag fold on the east limb of a still larger anticline. Campbell's brilliant analysis of this structure and of its violent reversal in plunge leads to the intriguing suggestion of a possible repetition of the productive structure a couple of miles to the southwest, a possibility that, according to reports, the Western Mining Corporation is now testing by drilling.

Not only in Kalgoorlie but in several other Western Australian districts, Campbell and his associates have worked out the mechanics of intricate folding. The 22 mile belt extending northward from Southern Cross was formerly a series of isolated mines. Now, as described by Clappison and Zani, it has become a tectonic unit with gold ore bodies occupying contorted structures somewhat reminiscent of the Homestake lodes in South Dakota. The feature of the folding is the waxing and waning of individual folds whereby a minor fold becomes a major one and vice versa when followed down the "pitch" (plunge to you).

Broken Hill.—The 154 pages dedicated by Haddon King and several associates to the Broken Hill District are no more than this richest of all lead-zinc-silver lodes deserves nor more than the excellent presentation merits. The structural peculiarity of the district is the intricate yet systematic scheme of folding with its extremes of thickening and thinning of beds and deformation of the fold axes themselves. Structural geologists who have not studied the paper by Gustafson et al. in the Bulletin of the Geological Society of America will do well to contemplate the present article as an example of a type of deformation that is probably more common than generally recognized, yet so bizarre that it would be offered to an incredulous world only by mining geologists able to substantiate it by detailed 3D sections. These structures, as mapped by the Central Geological Survey (an excellent example, by the way, of inter-company cooperation), are not notably modified in the new description except for certain relations of minor to major folds which several re-readings of the text have unfortunately failed to clarify to your correspondent.

Ever since Gustafson, Burrell and Garretty demonstrated so clearly that the ore conforms to certain consistent stratigraphic members and that each ore-bearing

member retains its characteristic mineralogy and metal ratio throughout, a puzzling question has remained without a wholly satisfactory answer: "How did replacing solutions manage to distinguish so emphatically between two adjoining ore-bearing members even where they are so intricately interfolded as to be minable in a single stope?" Burrell's answer was that each member had its own original sedimentary composition, notably its manganese content, and this influenced later replacement. Yet when traced beyond the ore bodies, the "favorable" beds cannot be distinguished from each other or even from the enclosing strata and manganese minerals are so closely associated with sulphides that most students have regarded them as part of the mineralization. To this problem King and Thompson come up with a new answer. The lead and zinc lodes were emplaced *before folding* "in some manner at present unknown," and acquired their present assemblage of characteristically high-temperature minerals through metamorphism associated with regional folding and granitic intrusion. This explanation, answering some, at least, of the baffling questions bears a resemblance to one of the many hypotheses that have been offered for Franklin, New Jersey, which with its suite of manganese silicates offers certain analogies. What, for example, would Leadville look like if its lead-zinc blankets with their manganiferous carbonate gangue were subjected to deep regional folding? *

Victoria.—The Bendigo goldfield with its famous saddle reefs is brought up to date through production records including that of the Deborah Reef which was discovered only in 1939 and is apparently the only one that was still being mined at the date of publication. An interesting point in Thomas' review is that despite production of an estimated 23 million ounces of gold during its hundred year history, Bendigo's profits from 1870 to 1951, as measured by excess of dividends over "calls," amounted to less than £3,000,000.

Because of the recent inactivity of the field it is not surprising that little has been added to prior concepts of structure. Regarding the still baffling problem of the localization of gold shoots amid the far greater volume of unpayable quartz, Stillwell concludes that the gold was precipitated by reaction between solutions and the residue from replacement of the host rock during the growth of the crystals that make up the vein quartz. Solutions depleted of their gold pass on to deposit low grade vein matter in the reef channels. Certainly there is much underground evidence of correlation between replacement of rock and deposition of gold; here, as in other gold-quartz deposits of medium to high temperature origin, the ore-shoots are marked by well-digested inclusions and well-replaced ribbon structures in contrast to the barren vein matter with its angular inclusions and sharp walls. The reviewer agrees with Stillwell that although fractures are necessary for the incoming of solutions in quantity, the growth of veins is a mechanism that does not *require* the presence of open spaces. But why should existence of open spaces be denied and what is the evidence for the flat statement that "open space filling and replacement do not readily blend"?

As Victorian goldfields other than Bendigo are little known outside Australia, the descriptions of a dozen or so of them provide instructive examples for comparison. There are all gradations from the symmetrical saddle reefs that develop in the Bendigo folds to the much less regular forms, like wierd caricatures of saddle reefs, that occur in rocks less symmetrically folded. In some, the mineralized reverse faults of a type that, in Bendigo, are subordinate to the saddles, become much more prominent and find their extreme development in rocks that offer no oppor-

* While the present review was in press there appeared a penetrating discussion of the Broken Hill section of the volume presenting objections to this interpretation. Gustafson, J. K., Discussion: Geology of Australian Ore Deposits—Broken Hill: Econ. Geol., vol. 49, November 1954, pp. 783–786.

tunity for slipping on bedding planes, i.e., the competent dikes of the Walhalla-Woods Point belt.

As these varied structures all appear to express the response of structurally different rocks to general east-west compression, it would seem unnecessary to resort, as does Thomas, to two periods of essentially identical gold mineralization, one before and one after the grantitic intrusion. Why not a single period of mineralization in accordance with the usual sequence: folding, intrusion, fracturing, mineralization? The single cited instance of gold veins in sedimentary rock ending at an intrusive contact might be explainable in other ways than by invoking a special state-wide pre-intrusive period of mineralization for the veins in the folded sediments. Apparently the classic picture of saddles opening during folding and the consequent assumption that mineralization accompanied folding is such a simple and beautiful concept that it dies a hard death.

Tasmania.—Mt. Lyell is another famous district of violently complex structure. There, J. M. Alexander develops the concept, attributable in part at least to Connolly, that folding on two axes intersecting at 40 degrees has resulted in a series of basins. The pyritic copper deposits are replacements of the schist by sulphides, localized at two main stratigraphic horizons at fold intersections.

Queensland.—The Mount Isa lead-zinc silver orebodies present a neat example of bedded replacements in deformed shales. Carter's article gives more information than was available at the time of Blanchard's writing regarding the relatively new copper orebody which occurs at depth. While lying within a few hundred feet of lead-zinc mineralization it differs from it both mineralogically and structurally and the two show no intergradational or zonal relationships to each other.

Thanks, largely, no doubt, to careful editing by A. B. Edwards which must have been a herculean labor of love, the book is virtually free of typographical errors or rhetorical blunders. It is somewhat confusing, though, that in accordance with old British custom, the term wolfram is used indiscriminately through the volume both for the element (W) and the mineral (FeMn)WO_4. Now that American chemists have sacrificed the word tungsten on the altar of international understanding, it would help if mineralogists would also follow international agreement and call wolframite by its accepted name.

The volume is well indexed; in fact it has not one, but two indices with the result that the unwary reader, looking up a locality, finds himself in the subject index approximately half the time but of course there is eminent if quite inexplicable precedent for this innocent snare.

But to take issue on a minor and controversial points is merely to indulge in one of the few diversions open to a reviewer. If all of the unexceptionable views and commendable features were given proportionate attention the review would be nearly as long as the book itself. Together with the Canadian volume it sets a high standard for the proposed successor to Ore Deposits of the Western States.

HUGH MCKINSTRY

R.O.T.C. BUILDING,
CAMBRIDGE 38, MASSACHUSETTS,
Sept. 15, 1954

Geologie der Schweizeralpen. By J. CADISCH and E. NIGGLI. Pp. 491, figs. 59. Wepf & Co., Basel, 1953. 44.–SFr.

Although, *sensu latu*, the term geology includes petrology as well, the new edition of Cadisch's Geology of the Swiss Alps could be called: Geology and petrology of the Swiss Alps, since the co-author, Prof. E. Niggli from the University of Leiden, is a petrologist. Dr. J. Cadisch is professor of geology at the University of Bern. Whereas the first edition (1934) was basically a textbook,

the new edition is more a handbook. The individual sections are written in such a way that they can be read and used separately and special care has been taken to refer to the important literature. For the following reasons the excellent section on petrology and mineralogy is of interest to the American mineralogist and petrologist: The summary on the petrology of igneous rocks (p. 21–80) and of metamorphic rocks (p. 80–119) of the Alps is the best, the most complete and up-to-date outline on this subject. It is not only a perfect review of what has been done so far, but also a good program for future research. The same is true for the section on sedimentary rocks (p. 120–188), and the rest of the book.

The volume is well illustrated and has few printing errors. It contains three sections: I. Introduction and generalities (p. 1–20). II. The "building materials" of the Swiss Alps (rocks, stratigraphy and tectonics) (p. 21–289). III. The landscapes (geomorphology) of the Swiss Alps (p. 290–444).

The section by Prof. E. Niggli includes outlines on the petrochemistry of igneous and metamorphic rocks of the Swiss Alps (by tectonic and/or regional units, partly as syntheses which are published for the first time). Also included is a brief summary on the famous fissure minerals (Kluft-mineralien), which are described in a new book by Prof. Parker, printed by the same publishers. It represents an almost complete coverage of the newer and, to a certain extent, also of the older literature. It is the most up to date guide to the literature and the problems of alpine petrology and mineralogy (and geology!), and should, therefore, be of interest to the American worker interested in this subject.

One thing that is almost completely left out, and which economic geologists and mineralogists will miss, is a brief summary on alpine ore deposits. Ore deposits connected with ophiolites are practically the only ones mentioned. Although the ore deposits of the Swiss Alps are not commercially important, they are, genetically and mineralogically, extremely interesting. Moreover, they play a rather important role in the discussion of the genesis of many gneisses and granites (palingenesis versus juvenile). Schneiderhöhn, in a recent publication, classified most Alpine ore deposits as being re-worked Paleozoic or even older deposits, whereas P. Niggli (in his unpublished guide for a field trip to Austria) presented many strong arguments for a young Alpine age of most Alpine ore deposits. A careful re-study of the numerous though small ore deposits could be used as one of the keys to many unsolved problems on Alpine petrogenesis.

In the section on petrology and mineralogy of the igneous rocks there are two things which strike the reader. Firstly, there is probably no other mountain belt in the world where the classical tools of the petrologist have been applied so thoroughly and carefully: the hammer and the map, the microscope and chemical analyses. Secondly, it is remarkable that, since Professor Niggli set this tradition in the twenties, many workers have, again and again, correlated their observations to the newest data of physical-chemistry.

On the other hand, other methods should be applied as well—many of which have been developed only recently and afford partly a close team work between universities, industry, and the state (because equipment needed is very expensive).

Some of these newer methods are: spectroscopic analysis of rocks and minerals (for trace element geology), mass spectroscopy (for isotope geology), age determinations, radioactivity measurements, assaying of ore deposits, drilling (for solving problems of tectonics, stratigraphy, and economic geology), field-emission microscopy, electron diffraction, and reflection-electron microscopy (for studies of solid surfaces), and differential thermal analyses. It is obvious throughout

the book (although rarely mentioned) that many problems of Alpine geology will never be solved without the application of one or more of these modern methods. To mention just two examples: 1) A relatively small number of age determinations could solve quite a number of vital problems, such as the age of the volcanic rocks in the Taveyannaz-sandstone, the age of the intrusive members of many nappes, of the Casanna-shists. 2) Whereas the geochemistry of the major elements of Swiss rocks, minerals and soils is relatively well known, the trace element geology is far behind. Yet, it is well known that many rocks and stratigraphic units can only be differentiated and/or genetically understood with the help of trace element composition determinations.

In conclusion, there is no better reference book and guide to Alpine petrology and mineralogy than the new, completely revised edition of Geologie der Schweizeralpen.

G. C. AMSTUTZ

PETROLOGIST,
CERRO DE PASCO CORP.,
CERRO DE PASCO, PERU,
Nov. 4, 1954

Second Conference on the Origin and Constitution of Coal. Pp. 399; figs.; charts; infolded maps. Nova Scotia Dept. of Mines, Crystal Cliffs, Nova Scotia, Canada, 1954.

This conference was held in June 1952 at the Center for Geological Sciences, under the joint sponsorship of the Nova Scotia Department of Mines and the Nova Scotia Research Foundation. A number of outstanding investigators in coal from many parts of the world were invited to participate, and this volume is the outcome of the papers delivered and the ensuing discussions.

The nature of the volume may be seen from the titles of the papers and the authors. They are: Coal Research in Europe by W. J. Jongmans of Holland; Geology of the Pittsburg Coal by A. T. Cross of West Virginia; Inverness Coalfield compared with Sydney coalfield by T. B. Haites of Sydney; Studies of Field Relations of Coal Beds by H. W. Wanless of Urbana, Ill.; Degradation of Plant Materials and Its Relation to the Origin of Coal by E. S. Barghoorn of Cambridge, Mass.; The Plant Microfossils of the Joggins Section: A Progress Report by L. R. Wilson of Amherst, Mass.; A Preliminary Study of the Spores from the Phalen Seam in the New Waterford District, Sydney Coalfield, Nova Scotia by Miss Grace Somers; Petrographic and Microchemical Studies of Coal by R. M. Kosanke; Mineral Matter in Coal by B. C. Parks; A Petrographic Investigation of the Tracy Seam of the Sydney Coalfield, Nova Scotia by P. A. Hacquegard; The Origin and Transformation of Bituminous Material in Coal by W. F. Seyer; X-Ray Diffraction Study of Rank Increase in Coal by R. Siever; and Problems in the Physical Chemistry of Coal by H. H. Storch.

The list of the titles and authors alone makes it evident that here is an outstanding and authorative group of papers covering a wide field of new thought on the origin and constitution of coal. This volume has certainly justified the calling of the conference and has done much to make the newer knowledge of the problems of the origin of coal available to others than the experts themselves. The volume is nicely printed on coated paper so that the many fine half tones are well reproduced. The sponsors are to be congratulated on this noteworthy volume.

Coal. By WILFRID FRANCIS. Pp. 567; illustrations. Edward Arnold, Ltd., London, 1954. Price, $17.50.

This comprehensive book brings together information on the formation and composition of coal, and coal environment. The 11 chapters deal with the origin of coal, the structure of coal-forming plants, chemistry of plant products, the formation and composition of peat and lignitous coals, the coal series—their structure, petrology and classification, composition of mature coals, normal and abnormal coal-forming processes, inorganic constituents, and physical considerations, along with an appendix on research procedures for detailed examinations of coals. Each chapter is followed by a group of references, many of which are long out of date.

Most of the newer information on coal is incorporated in this volume, but there is also included much older information that is left over from the predecessor volume, Monograph on the Constitution of Coal, by M. C. Stopes and R. V. Wheeler, which appeared before 1920. This is not a revision of the earlier volume, it merely follows its pattern and contains some of its material and references. It should prove a very useful book to all students of coal geology, coal chemistry, and fuel technology.

The Use of Stereographic Projection in Structural Geology. By F. C. PHILLIPS. Pp. 86; figs. 86. Edward Arnold, Ltd., London; St. Martin's Press, Inc., New York, 1954. Price, $3.00.

This little book, following a chapter on the principle of stereographic projections, deals with a series of problems on true and apparent dip, intersecting oblique planes, rotation of the sphere, rotation about inclined axes, and tectonic synthesis in stereographic projection. Each of the problems is well illustrated by clear drawings. At the end is an appendix on calculations by spherical trigonometry, and a list of exercises and answers. There are a bibliography and index. The explanations are clear and simplified and are illustrated by reference to some geological phenomena. The chapter on tectonic synthesis is of interest to petrologists as it deals with petrofabrics. The book should provide a ready reference for students of structural geology.

La Géologie et les Problémes de L'Eau en Algerie. Vol. I. Eléments de Technogéologie de Barrages Algériens. 19th Int. Geol. Congress. Algiers, 1952.

This post-congress monograph (8×11 inches) consists of 19 separate parts by 16 different authors, of which 15 parts deal with as many different projects, and 4 deal with related matters. Each part covers the geology and hydrology of the region, giving the stratigraphy, structure and hydrologic conditions. Other sections give the history, choice of dam sites, geologic technology of dam construction, and results. Pocket maps accompany each text. Each part follows similar outlines. To an arid country, such as Algeria, water, reservoirs, and dam construction are of prime importance and this monographic work brings together a large fund of information available for geologists and engineers, and for the selection of future dam sites and dam construction.

BOOKS RECEIVED

FRANK G. LESURE

U. S. Geological Survey—Washington, D. C., 1954

Prof. Paper 245. Geology and Ore Deposits of the Boulder County Tungsten District, Colorado. T. S. LOVERING and OGDEN TWETO. Pp. 199; pls. 27; figs. 135; tbls. 12. Price $9.50. *Detailed descriptions of Precambrian and Tertiary rocks and structure, mineralogy and origin of ore deposits and individual mine areas. Well illustrated by large scale colored geologic maps and mine diagrams.*

Prof. Paper 254-E. Cretaceous Foraminifera From the Greenhorn, Carlile and Cody Formations South Dakota, Wyoming. S. K. FOX, JR. Pp. 93–124; pls. 3; tbls. 4. Price 65 cts.

Prof. Paper 254-G. Foraminifera and Origin of the Gardiners Clay (Pleistocene), Eastern Long Island, New York. LAWRENCE WEISS. Pp. 143–164; pls. 2; figs. 4. Price 50 cts.

Bull. 986. Geology of the Jackson Area Mississippi. W. H. MONROE. Pp. 133; pls. 6; figs. 11. Price $1.75. *Stratigraphic and structural study of area surrounding Jackson gas field.*

Bull. 965-C. Petrology of Parícutin Volcano, Mexico. R. E. WILCOX. Pp. 281–353; pls. 2; figs. 13; tbls. 9. Price 30 cts. *Progressive change in composition of successive ejecta caused by combination of fractional crystallization of magma and assimilation of salic country rock.*

Bull. 975-C. Magnesite Deposits in the Serra das Éguas, Brumado Bahaia, Brazil. A. J. BODENLOS. Pp. 87–170; pls. 7; figs. 12; tbls. 14. Price $2.25. *Includes general geology of area, mineralogy and origin of magnesite deposits and description of individual deposits.*

Bull. 995-C. Geology and Mineral Resources of the Gasquet Quadrangle California-Oregon. F. W. CATER, JR., and F. G. WELLS. Pp. 79–133; pls. 5; figs. 2. Price 80 cts. *Petrology and structural geology of rocks associated with chromite, gold, copper, and quicksilver deposits.*

Bull. 995-E. Strippable Coal in Custer and Powder River Counties Montana. ANDREW BROWN and others. Pp. 151–199; pls. 5; figs. 17; tbls. 3. *Description of 11 areas where Tongue River beds are suited to strip mining.*

Bull. 995-F. Some Magnetite Deposits in New Jersey. P. E. HOTZ. Pp. 201–253; pls. 13; figs. 5; tbls. 5. Price $1.00. *Description of deposits based on geologic studies, dip-needle surveys and diamond drill hole exploration.*

Bull. 995-G. Strippable Lignite Deposits, Wibaux Area, Montana and North Dakota. P. R. MAY. Pp. 255–292; pls. 5; figs. 3; tbls. 4. Price 50 cts. *Detailed description of 2 deposits.*

Bull. 995-H. Three Deposits of Strippable Lignite West of the Yellowstone River Montana. W. C. CULBERTSON. Pp. 293–332; pls. 5; figs. 10; tbls. 3. Price 50 cts.

Bull. 995-I. Selected Deposits of Strippable Coal in Central Rosebud County, Montana. R. C. KEPFERLE. Pp. 333–381; pls. 5; figs. 15; tbls. 3. Price 60 cts. *Description of 9 deposits.*

Bull. 1004. Geology and Ore Deposits of the Willow Creek Mining District, Alaska. R. G. RAY. Pp. 86; pls. 9; figs. 29; tbls. 6. Price $1.75. *Description of general geology and mineral deposits with emphasis on vein, dike and fault patterns.*

Bull. 1005. Fluorspar Deposits of Utah. W. R. THURSTON and others. Pp. 53; pls. 8; figs. 18; tbls. 3. *Description of deposits in 4 areas.*

Bull. 1019-A. A Selected Bibliography on Quicksilver 1811–1953. M. JANE EBNER. Pp. 62. Price 25 cts.

Bull. 1022-A. Geophysical Abstracts 156 January–March 1954. MARY C. RABBITT *and others.* Pp. 70. Price 25 cts. *Abstract nos. 156–1 to 156–187.*

Bull. 1022-B. Geophysical Abstracts 157 April–June 1954. MARY C. RABBITT and others. Pp. 71–133. Price 25 cts. *Abstract nos. 157–1 to 157–201.*

Water-Sup. Pap. 1162. Quality of Surface Waters of the United States 1949. C. G. PAULSEN. Pp. 662; fig. 1. Price $2.00.

Water-Sup. Pap. 1164. Stage-Fall-Discharge Relations for Steady Flow in Prismatic Channels. W. D. MITCHELL. Pp. 162; figs. 45; tbls. 37. Price 50 cts. *Laboratory studies of effect of variable backwater on stage-discharge relations at stream-gaging stations.*

Water-Sup. Pap. 1185. Surface Water Supply of Hawaii 1949–50. C. G. PAULSEN. Pp. 128. Price 40 cts.

Water-Sup. Pap. 1218. Surface Water Supply of the United States 1951. C. G. PAULSEN. Pp. 332; fig. 3. Price $1.00.

Water-Sup. Pap. 1227-B. Floods of May 1951 in Western Oklahoma and Northwestern Texas. J. V. B. WELLS. Pp. 135–199; pl. 1; figs. 6; tbls. 2. Price 70 cts.

Water-Sup. Paper 1228. Geology and Water Resources of Smith Valley, Lyon and Douglas Counties, Nevada. O. J. LOELTZ and T. E. EAKIN. Pp. 88; pls. 3; figs. 6; tbls. 8.

Water-Sup. Paper 1261. A Postglacial Chronology for Some Alluvial Valleys in Wyoming. LUNA LEOPOLD and J. P. MILLER. Pp. 90; figs. 25; tbls. 9. Price 35 cts.

Report of the Committee on the Measurement of Geologic Time. Pp. 187. National Academy of Sciences—National Research Council. Pub. 319. Washington, D. C., 1954. Price $1.50. *Includes annotated bibliography of articles related to measurement of geologic time; abstracts of papers on geologic time presented 1953 Am. Geophysical Union; recent work on natural variations in isotope ratios; analyses of Brazilian radioactive minerals; and translations of one Japanese and 4 Russian papers on measurement of geologic time.*

Exploration and Development of Small Mines. H. E. KRUMLAUF. Pp. 34; figs. 8. Univ. of Arizona, Tucson, 1954. Price 25 cts. *Includes description of surface and underground exploration methods and costs and discussion of mining methods.*

Geology of the Siver Lake Talc Deposits, San Bernardino County, California. L. A. WRIGHT. Pp. 30; pls. 3; figs. 18. Division of Mines, San Francisco, 1954. Price $1.00. *General geology, mineralogy and petrography of talc deposits. Description of 8 mining areas.*

Univ. of Cal. Pub. in Geol. Sciences. Berkeley and Los Angeles. 1954

Vol. 29, No. 9. Mode of Origin of Pyroclastic Debris in the Mehrten Formation of the Sierra Nevada. G. H. CURTIS. Pp. 453–502; pls. 35–45; figs. 4. Price 75 cts. *Volcanic debris believed formed by autobrecciation of slowly moving lava.*

Vol. 30, No. 2. Foraminifera from the Gaviota Formation East of Gaviota Creek, California. E. J. WILSON. Pp. 103–169; pls. 7; figs. 3; tbls. 3. Price $1.00.

Vol. 30, No. 3. Anorthosite and Related Rocks of the Western San Gabriel Mountains, Southern California. DONALD V. HIGGS. Pp. 171–222; pls. 19–29; figs. 17; map 1; tbls. 3. Price $1.00. *Study of norite-anorthosite complex. Hypothesis of "Internal Explosion Shattering" advanced to explain protoclastic shattering of norite and anorthosite.*

The Morphology, Mineralogy and Genesis of Two Southern New England Soils. G. A. BOURBEAU and C. L. W. SWANSON. Pp. 59; figs. 19. Bull. 584. Conn. Agric. Exper. Sta., New Haven, 1954.

Illinois Geological Survey, Urbana. 1954

Petroleum No. 71. Oil and Gas Development in Illinois During 1953. A. H. BELL and VIRGINIA KLINE. Pp. 24; figs. 3; tbls. 7.

Rept. 169. Microanalysis of Organic Compounds Containing Fluorine. H. S. CLARK and O. W. REES. Pp. 19; figs. 4; tbl. 1.

Rept. 170. Petrology and Sedimentation of Upper Chester Sandstones. RAYMOND SIEVER. Pp. 207–219; figs. 6.

Rept. 174. Extension of Tazewell Glacial Substage of Western Illinois and Eastern Iowa. P. R. SHAFFER. Pp. 443–455; figs. 8.

Salem Limestone and Associated Formations in South-Central Indiana. T. G. PERRY, N. M. SMITH and W. J. WAYNE. Pp. 73; pls. 5. Indiana Geol. Sur., Bloomington, 1954. Price 50 cts. *Description of geomorphology of area and road log for 9 stops in Salem outcrop area. Includes detailed sections for each stop.*

Kansas Geol. Sur., Lawrence. 1954

Bull. 108. Geology and Ground-Water Resources of Wichita and Greeley Counties, Kansas. G. C. PRESCOTT, JR., J. R. BRANCH and W. W. WILSON. Pp. 134; pls. 7; figs. 13; tbls. 16.

Oil & Gas Inv. No. 11. Preliminary Study of the Structure of Western Kansas. WALLACE LEE and D. F. MERRIAM. Pp. 23; pls. 6; figs. 12. *Illustrated by structure and isopachous maps and cross-sections.*

Oil & Gas Inv. No. 12. Cross Sections in Eastern Kansas. WALLACE LEE and D. F. MERRIAM. Pp. 8; pls. 4; figs. 2. *One north-south and 3 east-west sections showing structural developments at successive periods of regional deformation leading to present structure.*

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Principal Natural Gas Pipe Lines of Penn. T. H. JONES and LILLIAN HEEREN. 1 sheet. Price 75 cts. *Oil and gas fields map scale 1 inch = 6 miles. Natural gas pipe lines map and crude oil and product pipe lines map scale 1 inch = 12 mi.*

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Bull. No. 140. Os Esporomorfos do Folhelho de Barreirinha. F. W. SOMMER. Pp. 49; pls. 2; figs. 8. *Description of spores found in Devonian black shales in State of Para.*

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Bull. No. 142. Consideracoes Sobre Alguns Lamelibranquios das Camadas Terezina No Parana. KARL BEURLEN. Pp. 41; pl. 1; figs. 2.

Bull. No. 143. Geologia das Quadriculas de Piracicaba E Rio Claro, Estado de São Paulo. F. F. M. DE ALMEIDA and OCTAVIO BARBOSA. Pp. 96; figs. 45; tbls. 7. *Stratigraphy and structure of 2 quadrangles, Piracicaba and Rio Clara in State of São Paulo. Includes 2 colored geologic maps, 20″ × 22″, scale 1–100,000.*

Bull. No. 144. Jazidas de Ferro do Brasil. L. J. DE MORAES and others. Pp. 66; figs. 3. *Location, brief description and reserves of iron ore deposits in Brazil.*

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SOCIETY OF ECONOMIC GEOLOGISTS

Abstracts of Papers to be Presented at the Joint Meeting of the Society of Economic Geologists and the American Institute of Mining and Metallurgical Engineers, Chicago Meeting, February 14–17, 1955

Program

Monday, February 14, 1955

Afternoon

1. Geological, mineralogical, and crystallographic factors in the exploitation of lepidolite deposits. E. W. Heinrich, University of Michigan, and A. A. Levinson, Ohio State University.
2. Tracing geological structures by geochemical means. Forbes Robertson, Montana School of Mines.
3. Alteration and mineralization in the Irwin District, Gunnison County, Colorado. Arthur A. Socolow, Boston University.

4–5. 2 papers not submitted through S.E.G.

Thursday, February 17, 1955

Morning

1. Mineral zoning in the Portage Lake lava series, Michigan copper district. Richard E. Stoiber and Edward S. Davidson, U. S. Geological Survey.

2–5. Four other papers not submitted through S.E.G.

Coal Committee Program

Thursday, February 17, 1955

Morning

Co-chairmen: Paul Averitt and Edward C. Dapples

9:00 1. Locating Quaternary cutouts in coal by seismic refraction method. Charles E. Weir * and Maurice E. Biggs, Indiana State Geological Survey.

9:20 2. Strippable coal reserves in the Fort Union region of Montana and North Dakota. William C. Culbertson, U. S. Geological Survey.

9:45 3. Behavior of petrographic components on North Dakota lignite in preparation, low-temperature carbonization, and steam-drying. Alfred Traverse, U. S. Bureau of Mines.

10:15 4. Microscopic studies of uranium-bearing coal deposits. James M. Schopf * and Ralph J. Gray, U. S. Geological Survey.

10:40 5. Geologic studies of coal mine roof shales. Jack A. Simon, Illinois State Geological Survey.

11:10 6. Origin of ash-forming ingredients in coal. Maurice Deul, U. S. Geological Survey.

* Speaker.

Afternoon

Co-chairmen: Elso S. Barghoorn and James M. Schopf

1:30 1. The isotopic geochemistry of carbon. Harmon Craig, University of Chicago.

2:00 2. A summary of the stable carbon isotopes in humic and sapropelic sediments throughout the geologic column. Kalervo Rankama, University of Helsinki.

(Combined discussion period for papers 1 and 2)

Symposium on Differential Thermal Analysis

3:00 1. Studies of carbonaceous materials by vacuum differential thermal analysis. Irving A. Breger, U. S. Geological Survey.

3:20 2. Some experimental factors that modify differential thermograms of bituminous coals. Kenneth E. Clegg, Illinois State Geological Survey.

3:40 3. Investigation of the coking properties of coal by vacuum differential thermal analysis. Lewis H. King,* Geological Survey of Canada, and Danford G. Kelley, Massachusetts Institute of Technology.

4:00 Panel discussion on differential thermal analysis of coal and carbonaceous materials.

GEOLOGICAL, MINERALOGICAL AND CRYSTALLOGRAPHIC FACTORS IN THE EXPLOITATION OF LEPIDOLITE DEPOSITS

E. WM. HEINRICH AND A. A. LEVINSON

Univ. of Michigan, Dept. of Mineralogy; and Ohio State U., Dept. of Mineralogy

The chief districts in the United States from which lepidolite has been produced are Maine, the Black Hills, Gunnison County, Colorado, Taos County, New Mexico, and the Pala district, California. Major areas of production or potential production in foreign countries include southeastern Manitoba, Canada, Varuträsk, Sweden, Haut Vienne, France, Karibib, South-West Africa, Southern Rhodesia, Portugese East Africa, Madagascar, and the Pilbara area, Western Australia. Lepidolite and lithian muscovite are restricted to complex pegmatites, i.e., those with both primary zones and secondary units. These uncommon complex pegmatites normally occur in the marginal zone of a district, close to the margins of the parent batholith, usually in bordering metamorphic rocks. Within individual pegmatites lepidolite typically is confined to secondary units, such as fracture fillings and replacement bodies, which have been localized by various primary structural features of the pegmatite. Cleavelandite or sugary albite, quartz and a wide variety of rare constituents are characteristic associates.

Two or more generations of lepidolite may occur in a single deposit, and each may be characterized by distinctive associates, macrostructural properties and composition, including the Li_2O content. Color in lepidolite is independent of the Li_2O content. Lepidolite occurs in four polymorphic structural types, which can be correlated with their Li_2O contents. Different polymorphs occur in different parts of the same deposit and even in different parts of the same book. X-ray studies can predict the approximate Li_2O content. Because of these small-scale variations in the nature and occurrence of lepidolite, detailed geological, mineralogical and crystallographic studies must be combined in order to obtain the maximum information on the localization, grade and quality of the deposits.

* Speaker.

TRACING GEOLOGICAL STRUCTURES BY GEOCHEMICAL MEANS *

FORBES ROBERTSON

Department of Geology, University of Washington, Seattle 5, Washington

Geological structures including contacts of intrusive rocks; "favorable" beds for replacement orebodies; and fissure veins can be traced by geochemical means in mining districts. A recent investigation to be published by Montana Bureau of Mines and Geology shows that concentrations of zinc, lead, copper, and manganese in soils collected systematically over the structures demonstrate distinct relationships which make it possible to locate the structures where they do not crop out at the surface but are covered by a residual soil mantle on grass or timber covered slopes.

In the Philipsburg district, the contact between intrusive granodiorite and Paleozoic limestones is marked by a strong concentration of metals in limestone over ore and by a small but conspicuous anomaly in a "barren" area. At Marysville, a contact of granodiorite with hornsfelsed Belt sediments is conspicuously marked by concentrations of gold and silver in the granodiorite.

The "Headlight Bed" in the Philipsburg district is the most favorable bed for replacement orebodies of manganese carbonates. Soil samples collected across known ore and a barren part of the bed reveal a very strong heavy metal anomaly over ore and a small yet distinct manganese anomaly in the barren area. Similar results are indicated from work in New World and Radersburg districts.

Fissure veins are detected from host rocks by minor concentrations of metals in the soils over barren areas, and by strong anomalies over known ore. Conspicuously successful results were recorded in tracing vein structures in sedimentary, metamorphic, and volcanic rocks.

ALTERATION AND MINERALIZATION IN THE IRWIN DISTRICT, GUNNISON COUNTY, COLORADO

ARTHUR A. SOCOLOW

Department of Geology, Boston University, Boston 15, Mass.

In this area a thick sequence of clastic sediments was invaded by a group of dikes, sills, and laccoliths, all acid in nature and genetically related. Following the intrusions, there was mineralized a system of fissures which had originated during a broad warping. Base metal and precious metal mining operations have developed here.

The large intrusions show so little in the way of distinctive contact effects that an insulating action by the early chill margins is suggested. The wall rock alteration by the solutions which mineralized the fissures, consists of silicification and sericitization; this alteration is restricted to well defined zones parallel to the fissure walls.

Pervading the rocks of the entire area is yet another type of secondary mineralization consisting in the development of epidote, chlorite, and pyrite. This would seem to fit the concept of propyllitization, even though the rock assemblage of the area is acid in nature. Structural and textural data indicate that much of epidote-chlorite-pyrite was brought in as such by hydrothermal solutions, rather than developed in situ at the expense of pre-existing minerals. It is suggested that this propyllitic type mineralization has developed in a thick, widespread zone over the roof of a deep-seated batholith, the very same mass which was responsible for the broad warping and fracturing.

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MINERAL ZONING IN THE PORTAGE LAKE LAVA SERIES, MICHIGAN COPPER DISTRICT

RICHARD E. STOIPER AND EDWARD S. DAVIDSON

U. S. Geological Survey, Norwich, Vt.; and Grand Junction, Colo.

In the Portage Lake lava series of the Keweenaw Peninsula, Michigan, three overlapping mineral zones—epidote, prehnite, and quartz zones, respectively—can be distinguished on the basis of the distribution of the void-filling minerals in flow tops. Higher stratigraphic horizons typically lie within the prehnite zone and lower horizons within the epidote zone. Temperature control of the distribution is suggested. Zone boundaries cross stratigraphic boundaries, indicating that these secondary minerals were deposited after many successive flows were extruded.

Copper concentrations revealed by mining and exploratory drilling are commonly near the boundary of the quartz zone. Concentrations well within the quartz zone are generally where quartz is not abundant. Most barren areas and unsuccessful mines lie either well outside the quartz zone, or where quartz or prehnite or both are plentiful.

Detailed mineral mapping of mines on the Kearsarge amygdaloid shows that quartz is a prominent mineral only in the deeper portions of the mined area. Major concentrations of copper lie near the boundary of the quartz area.

Mineralogy of flow tops of the Keweenawan series throughout the Lake Superior basin is like that of the Keweenaw Peninsula, indicating that the mineral zones have regional extent. The chemical constituents of epidote, prehnite, and quartz, and the wide distribution and post-extrusion age of these minerals suggest formation by hydrothermal rearrangement of material of the lavas. Copper distribution seems related to the zonal pattern resulting from this rearrangement and may itself be a product of the same widespread hydrothermal metamorphism.

LOCATING QUATERNARY CUTOUTS IN COAL BY SEISMIC REFRACTION METHOD [1]

CHARLES E. WIER AND MAURICE E. BIGGS

Indiana Geological Survey, Bloomington, Indiana

One of the most difficult problems that confronts a geologist in tracing the extent of a coal seam is that of locating cutouts in the coals if the cutouts are now filled with unconsolidated materials.

The southern part of the Rosedale quadrangle northeast of Terre Haute, Indiana, contains an area of flat upland to the east of the present Wabash valley. Here the Illinoian till overlain by windblown sand and loess completely conceals the bedrock channels which extend into the Wabash River valley. Only a small amount of drilling information is available.

The thickness of unconsolidated materials above bedrock was determined by seismic refraction shots along traverses through the area. Standard geophysical methods were used, but careful interpretation of the seismic records was required as the velocity of the seismic waves through the Pennsylvanian bedrock is only slightly greater than that through the unconsolidated material. Depth to bedrock was converted to altitude above sea level and a bedrock topographic map was made. A comparison of the bedrock topography with interpolated structure contours on the top of Coal III enable us to plot the extent line of Coal III.

This method is much faster and less expensive than drilling, but provides less detailed information and is precise to only ± 10 percent.

[1] Published with permission of the State Geologist, Indiana Geological Survey, Bloomington, Indiana.

STRIPPABLE COAL RESERVES IN THE FORT UNION REGION OF MONTANA AND NORTH DAKOTA

WILLIAM C. CULBERTSON

U. S. Geological Survey, Tuscaloosa, Ala.

The Fort Union coal region of Montana and North Dakota extends over about 60,000 square miles and contains an estimated 566 billion short tons of lignite and subbituminous coal in the Paleocene Fort Union formation. Much of this coal is suitable for recovery by large-scale strip mining methods because the overburden consists of poorly consolidated sandstone and shale and many of the coal beds are thick, flat-lying, free from partings, and persistent throughout large areas at shallow depths.

In 1950–1953 the U. S. Geological Survey mapped 27 deposits of strippable coal, principally in eastern Montana near the Yellowstone River, that contain a total of 5.3 billion short tons of lignite and subbituminous coal under less than 120 feet of overburden and that have a total area of 260 square miles. About 48 percent of these reserves, or 2.5 billion tons, are under less than 60 feet of overburden. The 27 deposits range in average thickness of coal from 6 to 25 feet. The minimum thickness of coal within a deposit is 5 feet.

These reserves represent only a small fraction of the total strippable reserves in the Fort Union region, for most of the region either is unexplored or has been explored only on the surface. Exploration of this region by drilling would undoubtedly increase the known strippable reserves greatly, perhaps tenfold.

BEHAVIOR OF PETROGRAPHIC COMPONENTS OF NORTH DAKOTA LIGNITE IN PREPARATION, LOW-TEMPERATURE CARBONIZATION AND STEAM-DRYING

ALFRED TRAVERSE

Lignite Research Laboratory, U. S. Bureau of Mines, Grand Forks, N. D.

It has been shown that anthraxylon is much the least grindable or toughest of the petrographic components of Fort Union lignite, with translucent attritus somewhat more grindable, and opaque attritus and fusain the most grindable or friable. The toughness of lignitic anthraxylon contrasts with the characteristic brittleness of anthraxylon (vitrain) of bituminous coals. This is one indication that microscopically identified components of coal have some uniformity of nature only within one coal rank. Petrographic composition of lignite has considerable influence on yield of tars, light oils, and gases, in laboratory 500° C carbonization assay. Further sub-classification of translucent attritus will be essential in order to demonstrate the origin of some of the volatile substances obtained on carbonization. Experiments on the Fleissner steam-drying process were carried out with selected samples of known petrographic composition, at steam pressures of 400, 1,000, and 1,500 pounds-per-square-inch. This process removes moisture from lignite, yielding a stable, non-slacking product. Drying at 400 psig causes very little structural alteration in the coal, despite removal of about 68% of the moisture and consequent increase in "rank." Drying at 1,000 and 1,500 psig, which removes almost 90%, and almost 100% of the moisture, respectively, causes great structural alteration which is closely related to petrographic composition. The translucent components are much more subject to "bloating"—formation of vesicular structure at high pressures—than are the opaque components.

MICROSCOPIC STUDIES OF URANIUM-BEARING COAL DEPOSITS

JAMES M. SCHOPF AND RALPH J. GRAY, U. S. GEOLOGICAL SURVEY

Coal Geology Laboratory, Columbus, Ohio

A detailed study of petrologic composition of four uranium-bearing lignite beds in South Dakota suggests that the most highly degraded types of plant material are most favorable for uranium emplacement. No quantitative relation exists between standard coal petrologic constituents and amount of uranium, but these constituents have been determined as a basis of comparison with other American coal deposits. The beds studied are unusually variable in their petrologic composition.

A method for the further integration of translucent attritus, the most heterogeneous of the standard coal petrologic entities, has been applied to coal layers of contrasting uranium content. This may eventually show the degree of uranium receptivity characteristic of various microscopic components. However, the controlling factors evidently are complex, and only a general preference of uranium for types of degraded organic matter is now apparent.

GEOLOGIC STUDIES OF COAL MINE ROOF SHALES[1]

J. A. SIMON

Illinois State Geological Survey, Urbana, Illinois

The geologic factors which affect the strength of coal mine roof have been studied by investigating strata immediately overlying Herrin No. 6 coal in southern Illinois. Shale is the principal material studied because of its range of behavior characteristics. Attention is directed to the importance of knowledge of geologic factors as a supplement to engineering data in predicting mine roof behavior and in controlling strata in coal mines.

Two major phases of the study are: 1) recognition and description of pertinent geologic features such as faults, slips, fracture patterns in coal or roof, "horsebacks," "whitetop," "clod," "rolls," splits, washouts, "rider" seams, degree of lamination, groundwater relationships, concretions, strata associated with the roof; and 2) quantitative evaluation of roof shales in respect to water absorption characteristics, clay mineralogy, grain size, relative strength, and effect of alternate wetting and drying.

Analysis of data obtained from nearly 400 samples taken from about 70 coal mines is presented. Simple measurements of slacking and water sorption characteristics give an indication of the presence or absence of swelling types of clay minerals.

The value of using qualitative and quantitative tests on diamond drill cores obtained from prospect drilling for new mining developments is emphasized.

THE ORIGIN OF ASH-FORMING INGREDIENTS IN COAL

MAURICE DEUL

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Coal, upon ashing under standard conditions, yields gases and ash. The gases are largely composed of carbon, hydrogen, and oxygen with sulfur, nitrogen, chlorine, fluorine, and other volatile elements contributing only a small percentage. Ash,

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in past usage, has been equated to total mineral matter. It has long been recognized that the ash included separable minerals and inherent mineral matter. Until recently little attention has been given to studies of inherent mineral matter.

Inherent mineral matter contributing to ash actually consists of (1) inseparable minerals and (2) nonvolatile elements organically combined, complexed, or base-exchanged. These nonvolatile elements may include:

A. Elements present in living plants and not completely lost during degradation.
B. Elements combined with organic matter during degradation.
C. Elements combined during compaction and burial.
D. Elements combined during weathering.

Separable or extraneous mineral matter is the major contributor to the ash of coal. Oxygen, silicon, aluminum, iron, calcium, magnesium, sodium, and potassium usually make up 98 percent of the weight of coal ash except where very high sulfur and calcium contents permit the formation of calcium sulfate.

The enrichment of trace elements in coal ash probably results from combination of these elements with organic matter during degradation, during compaction and burial, and during weathering. Separates of minerals and organic matter from coals have been prepared and the ash of organic separates compared with original coal ash and with ash of separable minerals is: *always* enriched in B, Be, Fe, Na, Sc, U; *usually* enriched in As, Ce, Ge, Ti, Zr; *occasionally* enriched in Co, Ni, Mn, Mo, Pb, Sn, Sr, Y, Yb; and *never* enriched in Ca. Although there is scant evidence for how and during what stage of coalification some of these elements were combined with the coal, there is good geochemical evidence to explain how and when Fe, U, and Ge were introduced.

THE ISOTOPIC GEOCHEMISTRY OF CARBON

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The isotopic ratio C^{13}/C^{12} varies by about 5% in nature due to isotopic differentiation in the cycle of carbon. In the extraction of carbon from the ocean-atmosphere exchange reservoir, a fractionation results such that light carbon goes into shale, coal, and petroleum, and heavy carbon into limestones, with a resultant difference in C^{13} content of about 3%. The major application of these observations to geologic problems involves the study of the rate and mechanism of formation of the present atmosphere and ocean by "natural" isotopic tracer techniques, but many specific problems dealing with shales, limestones, graphites, etc., may also be attacked. The possibility of distinguishing terrestrial from marine plant remains in shales is currently being studied.

The isotopic data do not furnish a means of determining the organic or inorganic origin of carbon in ancient rocks. Thermodynamic data show that graphite cannot be formed by simple thermal dissociation of limestone; a reducing substance is required which in general has most probably been organic material. The actual problem is to distinguish between graphite of organic origin and graphite derived from igneous or primeval inorganic carbon. The possibility of isotopic fractionation during the formation of graphite, and the fact that igneous rocks contain light carbon while meteoritic carbon and terrestrial graphites cover the whole range of isotopic variation, make the deduction of the origin of ancient carbon deposits from isotopic data impossible. Most of these deposits probably represent organic accumulations, and it is possible to derive important information as to the constancy of the composition of the exchange reservoir of carbon from the isotopic data on material for which good geologic interpretation is possible.

A SUMMARY OF THE STABLE CARBON ISOTOPES IN HUMIC AND SAPROPELIC SEDIMENTS THROUGHOUT THE GEOLOGIC COLUMN

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A review is presented of the isotopic constitution of carbon in humic and sapropelic sediments and in their metamorphic derivatives of different age. There appears to be a continuous sequence of biogenic sapropelic carbon extending from very ancient Precambrian rocks to present-day sediments and another continuous sequence of biogenic humic carbon starting with the development of land plants.

STUDIES OF CARBONACEOUS MATERIALS BY VACUUM DIFFERENTIAL THERMAL ANALYSIS

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Conventional differential thermal analysis of carbonaceous substances may be accompanied by combustion of the material with resultant distortion of the exothermic-endothermic record. To avoid this difficulty differential-thermal-analysis equipment has been designed for operation in vacuo or in an inert atmosphere. Operation of the equipment under vacuum is advantageous because combustion of the sample is prevented, a standard atmosphere is maintained above the material being analyzed, and primary decomposition products are removed from the vicinity of the sample as quickly as they are formed thus eliminating secondary reactions which would tend to obscure the differential curve. The sensitivity of the curves obtained with the instrument that is described can be varied by changing such parameters as sample size, rate of heating of the furnace, and amplification of the differential record. In this manner it is possible to exaggerate specific portions of a curve for closer observation. Most analyses have been obtained with 20-mg samples and a furnace heating rate of 15°/min.

Differential thermal analysis of carbonaceous materials results in a gross decomposition spectrum of the sample that is diagnostic. The cause of individual peaks in the differential curve can be ascertained by means of complementary chemical analyses or by such other techniques as thermal gravimetric analysis. Where such specific information is not required, however, differential thermal analysis still provides a ready means of comparison between unstructured carbonaceous materials of unknown origin and composition or between two or more similar materials. A great advantage of the technique lies in the fact that no chemical work is required in preparation for the analysis, especially as prior chemical treatment may tend to alter the nature of the material under investigation.

SOME EXPERIMENTAL FACTORS THAT MODIFY DIFFERENTIAL THERMOGRAMS OF BITUMINOUS COAL*

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Preliminary investigation of differential thermal analyses of bituminous coal has demonstrated that the recorded thermogram is strongly influenced by experimental factors.

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Peak shifting and variation of temperature range of reactions occurred with changes in the rate of temperature rise of the furnace, degree of dilution of the sample, manner of covering the sample, depth-diameter ratio of the sample holder, and degree of packing of the sample.

A series of progressively altered thermogram types was obtained by manipulating these experimental factors. Curves fitting into this series were then produced by progressively altering one factor at a time while keeping all others as nearly constant as possible. Any one thermogram type could be reproduced with reasonable accuracy as long as constancy of all experimental factors was maintained, but difficulty was experienced in controlling hand packing of the sample.

It is suggested that the ultimate cause of variation of the thermograms is related to the ease and manner in which evolved gases are permitted to escape from the sample. These studies emphasize the necessity of extreme care in keeping all experimental conditions constant if thermal studies of bituminous coal are conducted under conditions that may impose restraint upon physical alteration of the sample during heating.

INVESTIGATION OF THE COKING PROPERTIES OF COAL BY VACUUM DIFFERENTIAL THERMAL ANALYSIS

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Vacuum differential thermal analysis has been used to study the coking properties of a number of bituminous coals. Samples of 200 mgs. were run from room temperature to 600° C using a heating rate of 10°/min.

The thermograms show two peaks that can be related to the plastic properties: (1) a strong exothermic peak beginning between 340°–440° C and reaching a maximum height between 440°–520° C; (2) a small, sharp exothermic peak superimposed on the limb of the larger peak and occurring between 430°–500° C. The beginning of No. 1 peak represents the softening temperature of the coal while its summit corresponds to the solidification temperature. No. 2 peak occurs in the temperature zone of maximum fluidity and maximum rate of swelling. The sharpness of this peak is influenced by the fluidity of the coal.

The changes that occur in the plastic properties of a coal through blending with other coals can be detected on the thermograms and in the small coke buttons formed in the thermocouple well. For example, by blending a high-volatile A coal with increasing amounts of a low-volatile coal, No. 2 peak occurs at progressively higher temperatures, diminishes in intensity and finally disappears. The coke buttons show changes in the cell structure and degree of swelling.

The thermograms and coke buttons can also be modified by the addition of diluents such as fusain, silica gel, quartz, clay, sulfur, charcoal, various inorganic salts and phenanthrene. The degree to which the thermal curves are affected depends on the type and amount of diluent, as well as the properties of the original coal.

SCIENTIFIC NOTES AND NEWS

THE PITTSBURGH GEOLOGICAL SOCIETY will conduct a pre-A.A.P.G. Convention field trip across the Appalachians from Pittsburgh to New York City. The trip will follow the Pennsylvania Turnpike to Harrisburg for an overnight stop. Eastward from Harrisburg, the group will travel on U. S. Route 22 to Easton, and from there on New Jersey Route 24 to Hackettstown and on U. S. Route 46 to New York. All travel will be in buses which will leave Pittsburgh Saturday morning March 26 and arrive in New York about 5 P.M. Sunday, March 27. Strata ranging from Precambrian through Triassic, including an almost complete Paleozoic section, will be studied. Physiographic provinces to be crossed are the Allegheny Plateau, Valley and Ridge, Reading Prong of the New England Upland and the Triassic Lowland. A guidebook with a detailed log of the entire trip will be available. Attendance is limited to 100.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, Society of Exploration Geophysicists, and the Society of Economic Paleontologists and Mineralogists will hold their Annual Meetings at the Hotel Statler, New York, March 28–31, 1955. The theme of the 1955 Annual Meetings is the "Habitat of Oil in the Sedimentary Basin." In line with this theme, authoritative papers are being prepared on the majority of the producing basins of the world, and the Research Committee of the A.A.P.G. is arranging a half-day, 6 or 7 paper symposium by outstanding authorities on the late Quaternary geology of modern depositional basins. Several papers are expected from research laboratories on the results of studies extending the frontiers of our knowledge. Other featured speakers are contemplated.

THE ROCKY MOUNTAIN SECTION of the American Association of Petroleum Geologists will hold its Fifth Annual Meeting at Billings, Montana, February 14–16, 1955. The theme "Milestones and Guideposts in Exploration" will be stressed by technical papers on recent exploration and development programs in the Rocky Mountain Areas. Some 23 papers will be presented.

THE UNIVERSITY OF MINNESOTA'S DEPARTMENT OF GEOLOGY and its Center for Continuation Study, in cooperation with the Minnesota Geological Survey, will conduct an Institute on Lake Superior Geology on April 1–2, 1955. The program for April 1 will include several papers on modern ideas of the stratigraphy and origin of iron formations and ores of the Lake Superior district by Harold L. James, David White, Burton Boyum, Stanley Tyler, and others, and conclude with a panel discussion on geophysics as applied to the Lake Superior district. April 2 will be devoted primarily to short papers on research now in progress on problems of Lake Superior geology. It is hoped that a number of people working on a problem in the Lake Superior district will offer a 5 to 15 minute summary or report of progress for this part of the program. Titles should be sent to Professor George M. Schwartz, Department of Geology, University of Minnesota, Minneapolis 14, Minnesota. An abstract should be sent not later than March 1, 1955. Carl Dutton, Regional Geologist, United States Geological Survey, has agreed to act as chairman for the institute.

WALLACE E. PRATT was awarded the American Petroleum Institute Gold Medal for Distinguished Achievement at the Annual Meeting of the Institute at Chicago on November 10.

VIRGINIA Ross has received a fellowship at the Department of Chemistry, Brown University, Providence 12, R. I., where she will continue her studies on the crystal-chemistry and geochemistry of the sulphide minerals. Mrs. Ross has formerly conducted this research in the Departments of Geology at M.I.T., Yale University and Harvard University.

FRANK NOE, formerly mineral attaché to Mexico, has been transferred to New Delhi.

ANNAN COOK became District Geologist for the Bear Creek Mining Company for the Southwestern United States with San Francisco as the base for operations. Formerly he held the same position with the same company in charge of exploration in the Eastern United States.

CLIFFORD S. LORD has been appointed Chief Geologist of the Geological Survey of Canada to succeed Dr. George Hanson, who became Director of the Survey in October 1953. Dr. Lord will be responsible mainly for organizing and directing the field work of the Survey.

EDWARD C. JONAS has been added to the staff of the University of Texas as assistant professor.

FRANCIS L. WHITNEY, Professor Emeritus of the Geology Department of the University of Texas, was honored at a Geology alumni dinner in Austin when he received from the alumni a grant of $250 per month for 12 months in order to complete his research on the Cretaceous stratigraphy and paleontology of Texas. In addition, the Humble Oil & Refining Company granted $5,000 to the University of Texas Geology Foundation to be used for research for Dr. Keith Young and for help to complete the maps and reports resulting from the long years of Dr. Whitney's Cretaceous stratigraphical and paleontological studies.

ED OWEN, consulting geologist of San Antonio, is again acting as lecturer without pay at the University of Texas for the school year 1954–55. He is conducting a special seminar on the Structure and Functions of the Oil Industry.

WALTER D. KELLER, Professor of Geology at The University of Missouri, was a special lecturer and guest professor at The University of Texas in October, giving lectures on geochemical weathering and the geology of uranium.

THE STANDARD OIL COMPANY OF TEXAS has generously donated $750 to the University of Texas Geology Foundation for the promotion of basic geological research.

ROY B. YOUNG has been named general manager of Quebec Iron and Titanium Corp., succeeding F. E. Walling.

FRANK COOLBAUGH, vice president-western operations of Climax Molybdenum Co., has also been elected president and a director of Climax Uranium Co. He replaces John H. White, Jr., who resigned.

DAVID C. SHARPSTONE, consulting geologist to the Ventures group and chairman and managing director of Kilembe Mines Ltd., has been appointed a director of Uganda Development Corp. through an order in council of Sir Andrew Cohen, Governor of Uganda.

A. F. BANFIELD and ROLAND F. PARKS, of Behre Dolbear & Co., have been in Labrador, doing field work in connection with a valuation of ore deposits.

A. W. WITHERSPOON, in active association with Hecla Mining Co., Wallace, Idaho, since 1931, has retired from the board of directors. He is succeeded by R. N. Hunt, director, vice president and chief geologist of U. S. Smelting, Refining and Mining Co.

GEORGE V. KELLER, geophysics branch, U. S. Geological Survey, Washington, D. C., has been transferred to Denver.

ELTON A. YOUNGBERG has been named director of the Mining Div. of the Grand Junction, Colo., operations office of the Atomic Energy Commission. Before joining the AEC in 1952, Mr. Young was with the U. S. Geological Survey as geologist in charge of the Juneau, Alaska, office and survey member of the Defense Minerals Exploration Administration field team that administered the DMEA activities in Alaska.

ERIK STENSIO, Swedish professor of geology, has been awarded the Wollaston medal by the Geological Society of London.

RALPH I. CLARK, mining geologist, is with the Pacific Northwest Area, Gladding, McBean & Co., Seattle. He was with San Luis Mining Co., Tayoltita, Durango, Mexico.

ROBERT M. HURST, who was with Miami Copper Co., Miami, Ariz., is a partner in Technical Services Inc., Grand Junction, Colo. This firm does engineering and geological work for independent uranium miners in the Colorado Plateau.

JOHN B. BOTELHO, mining geologist, has accepted a position in Brazil as field engineer with American and Foreign Power Co. on the Peixoto project. He was field engineer with Bateson & Stolte, Oakland, Cal.

WAYNE R. ABBOTT, Oklahoma geophysicist and geologist, is general manager of field operations for Amuranium Corporation, new Colorado Plateau uranium company.

F. W. LIBBEY, director of the Oregon department of geology and mineral industries, retired November 1. He was succeeded by Hollis M. Dole, acting director.

DAVID P. CRUZ, senior geologist of the Philippine Geological Survey, has tendered his resignation in order to become general superintendent of a private mine.

R. F. TEGENGREN, geologist of the Bolidens Gruvaktiebolag and the Companhia Boliden de Mocambique Lda., has been in Lisbon in connection with the company's application for an exclusive mineral concession in the Tete district of Mozambique.

PAUL T. WALTON, Salt Lake City, Utah geologist, has returned from Ethopia, where he conferred with Emperor Haile Selassie about the possible exploration and development of uranium mining in that country.

ALEXANDER J. SPEAL, mining geologist with Tungsten Mining Corp., Henderson, N. C., is with the Atomic Energy Commission, Hot Springs, S. D.

D. ABBOTT is field geologist, Anglo American Corp. Ltd., Johannesburg, Union of South Africa. He was with South West Africa Co. Ltd., Grootfontein, S. W. Africa.

THOR H. KIILSGAARD, formerly project chief, Defense Minerals Activities Northwest Region, U. S. Geological Survey, Spokane, is staff assistant, Defense Minerals Exploration Administration, USGS, Washington, D. C.

DAVID C. SHARPSTONE, consulting geologist to the Ventures Group and chairman and managing director of Kilembe Mines Ltd., has been appointed a director of Uganda Development Corp. through an order on council by Sir Andrew Cohen, Governor of Uganda.

P. T. FLAWN has taken a leave of absence for three months from the Bureau of Economic Geology, University of Texas, Austin, as consulting geologist with the Surface Geological Co., Albuquerque.

RALPH J. HOLMES, a member of World Mining Consultants Inc., New York, recently headed a mission that completed a comprehensive mineral resource survey of Somalia for the Italian Government. GABOR DESSAU of Rome was also a member of this group. A program of exploration of tin, iron ore, ilmenite, and barite deposits was recommended.

DONALD H. MCLAUGHLIN, president of Homestake Mining Co., San Francisco, has been named a director of Western Air Lines Inc.

PHILIP W. CHASE, director, exploration and development with U. S. Steel in Pittsburgh, has been appointed assistant vice president, Raw Materials, U. S. Steel Corp.

LEON BOUVIER, geophysicist for the Compagnie de Geophysique, Paris, France, has returned to France after spending six weeks in Denver, Colorado, studying the field and laboratory techniques of the Geochemical Exploration Section, U. S. Geological Survey.

THEODORE B. COUNSELMAN, mining and metallurgical engineer, announces that he has left the Dorr Company on January 1, 1955, to engage in consulting engineering in the mineral industries as an Associate Member of Gehre Dolbear and Company.

The RICE INSTITUTE has received a gift of $1,000,000 from Mrs. J. A. Elkins, Jr., Mrs. Wm. Francis, Jr. and Mrs. Lloyd Smith, daughters of the late Harry C. Wiers for whom a chair of geology was established in 1952 by Mrs. Wiers. $750,000 of the gift is for a new geology building which is expected to be ready by the fall of 1956.

C. S. PITCHMUTHER, Director of the Department of Geology, State of Mysore, has been appointed Professor of Geology at Central College, Bangalore, India.

PHILLIP L. MERRITT, Assistant Director for Exploration in the Atomic Energy Commission's Division of Raw Materials, has resigned to accept a position as senior geologist with E. J. Longyear & Co., of Minneapolis, Minn., consulting geologists and mining engineers. Dr. Merritt will maintain offices in New York City. Mr. Robert D. Nininger, who has been Deputy Assistant Director for Exploration, is Acting Assistant Director in Dr. Merritt's place.

JAMES M. MITCHELL has been appointed Assistant to the Director of the National Science Foundation. His responsibilities will be largely concerned with the Foundation's program of fact-finding studies on scientific activities and manpower in government, industry, and universities.

PHILLIP L. MERRITT has been appointed to the staff of E. J. Longyear Company, Minneapolis, as a senior geologist to initiate consulting services in the company's New York offices in the Graybar Building. Dr. Merritt has been Assistant Director of the Raw Materials Division of the Atomic Energy Commission since its inception and has directed the Commission's uranium exploration program.